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A STUDY OF THE EFFECTS OF FABRIC GEOMETRY VARIABLES ON AIR PERMEABILITY

WILLIAM O. PERRY

MATERIALS LABORATORY

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PROJECT No. 7320
TASK No. 73201

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
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FOREWORD

This report was prepared by the Functional Textiles Section, Textiles Branch, Materials Laboratory, WADC. It was prepared to present a summary of a part of the internal research effort of the Materials Laboratory. The work described herein was initiated under Project No. 7320, "Air Force Textile Materials", Task No. 73201, "Textile Materials for Parachutes", formerly RDO No. 612-12, "Textiles for High Speed Parachutes", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. William O. Perry acting as project engineer.

Through the diligent efforts of Mr. H. J. Bickford of Cheney Brothers, Manchester, Conn., the test fabrics for this study were supplied to this Center.

Sgt Blotner and his assistants of the Technical Photographic Section, WADC, capably assisted the author in accomplishing this work.

This report covers work conducted from March 1953 to February 1954.

ABSTRACT

A series of specially designed nylon parachute fabrics was selected to represent extremes in cloth construction and to demonstrate fundamentals of fabric geometry.

By means of a somewhat unusual test arrangment it was possible to indicate the relationship of fabric geometry to air permeability at several pressure differentials. Through the process of establishing the ratio of total fabric area to interstice area, data were obtained on yarn widths as they lie in the cloth. These data were obtained on a variety of twist constructions and will provide a knowledge and background of design data for present application and future studies in this area.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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I INTRODUCTION

A. OBJECTIVE

The object of this work was to provide data to show the effects of fabric geometry variables on the air permeability of certain types of parachute cloth. It was intended that the data obtained would be helpful and expeditious in fabric designing, and the predicting of air permeability. The ultimate goal of this type of work is to gain the necessary knowledge and ability to engineer fabric constructions to meet certain prescribed air permeability requirements without having to resort to costly trial and error methods. The ultimate goal was not realized from the work described herein but rather it constitutes some of the basic knowledge necessary for future programs in this field of endeavor.

B. DEFINITION OF TERMS

In this report the following terms and definitions will apply:

Permeability: The volume rate of air flow through unit area of cloth ($ft^3/min/ft^2$).

Open Area: The area of the open spaces or interstices normal to the direction of air flow, expressed as a percentage of the total fabric area.

Fabric Geometry: The yarn dimensions as they lie in a fabric, and that which may be changed by twist variations and fabric finishing operations.

Other factors such as weave, thread count and yarn size are also included.

II LITERATURE SURVEY

It has been shown, in an article written by F. T. Peirce for the Journal of the Textile Institute, 1937, 3, T 49, that the area covered per unit area of cloth by the two sets of yarns, can be calculated if the yarn widths and the thread count are accurately known. The result of this calculation is called the "Cover Factor" after Peirce. It follows then that the difference between the cover factor for a given area itself, would be the open space area in the cloth. It is this theory which was used as a basis for this investigation into the effects of fabric geometry on air permeability.

III EXPLANATION AND DERIVATION OF OPEN AREA CALCULATIONS

Figure I represents one square inch of a given cloth with a known number of warp and filling threads per inch. If the warp and filling threads of one square inch of cloth were to be jammed together, so to speak, the effect would be similar to that shown in Figure I. This leaves part of the square inch area uncovered by any warp or filling threads. If the value of this open area is known, it will be assumed that it can in some way be related to air permeability. In theory then, the open area is proportional to the thread count and the yarn widths, and may be expressed in the following form: $OA = 1-[(TC_w \times D_w) + (TC_f \times D_f) - (TC_w \times D_w)(TC_f \times D_f)]\ 100$ (1) where the bracketed term equals the "Cover Factor" and

TC_w = Warp thread count

TC_f = Filling thread count

D_w = Warp yarn width

D_f = Filling yarn width

OA = Percent open area

In order to test this scheme, suitable apparatus, fabrics and photographic assistance were obtained by Materials Laboratory personnel, for the purpose of obtaining accurate yarn width measurements so that open area values for a series of nylon fabrics, could be determined from the above equation.

IV APPARATUS

An experimental air permeability machine with a pressure differential capacity of 20 inches of water was used for this study. This instrument is shown in Figures 2 and 3. The photographic set up is shown in Figure 4.

V DESCRIPTION OF NYLON FABRICS USED IN THIS INVESTIGATION

A. GENERAL DESCRIPTION

The fabrics were manufactured to meet Specification MIL-C-7020, Type II, except that twist variations were inserted in the warp and filling yarns. This specification describes nylon parachute cloth weighing 1.6 ounces per square yard and is used in the fabrication of parachutes. The twenty-eight (28) different fabrics were woven and finished by Cheney Brothers, Manchester, Conn.

B. KEY TO SAMPLE NUMBERS

Twist in warp yarn

7 = 7 turns per inch of throwster's twist in Z direction

10 = 10 turns per inch of throwster's twist in Z direction

Finish

N = Not calendered

C = Calendered

Twist in filling yarns

1/2 = 1/2 turn per inch of producers twist in Z direction

2 1/2 = 2 1/2 turns per inch of throwster's twist in Z direction

5 = 5 turns per inch of throwster's twist in Z direction

Example: Sample 7C15 has 7 turns of Z twist per inch in the warp ends, was calendered in finishing and has 15 turns of Z twist per inch in the original filling yarn.

C. DESCRIPTION OF WARPS

All of the samples of cloth with 7 turns per inch in the warp yarn were woven from the same warp.

All of the samples with 10 turns per inch in the warp yarn were woven from the same warp.

The basic yarn in each of these warps was 40 denier, 13 filament, Type 200 nylon.

Each warp was made with the following ends:

Selvedge	36	ends
Body	4572	ends
Selvedge	36	ends
Total	4644	ends

+2 colored identification threads in each selvedge.

The 7 turns per inch warp samples were woven on a 56" Crompton and Knowles single - shuttle speed loom.

The 10 turns per inch warp samples were woven on a 46" X D Draper single shuttle loom.

D. DESCRIPTION OF FILLING

All samples were woven with 72 picks/inch in the loom. The basic yarn was 70 denier, 34 filament, Type 200 nylon in samples with 5 and 7 turns of twist. All other samples were made with Type 100 nylon, same denier and filament count.

E. CUTS

The samples were woven in four separate cuts:

Cut 1 - Samples 7N1/2 through 7N35 inclusive

Cut 2 - Samples 7C1/2 through 7C35 inclusive

Cut 3 - Samples 10N1/2 through 10N35 inclusive

Cut 4 - Samples 10C1/2 through 10C35 inclusive

Each cut was processed through all operations without separating individual samples until after finishing.

F. FINISH

All samples marked calendered, were calendered in the greige with a hydraulic pressure of 80 tons and with steel roll temperatures of 190 - 210 °F. The cloth was passed through the pressure points of the rolls twice. The cloth was then jig scoured, crepe dried at 240 °F, 70 yards per minute, and finally steam tentered.

All twenty-eight (28) samples were tested at Cheney Brothers for filling twist, air permeability at 0.5 in. pressure differential, thickness and thread count. These data are shown in Appendix I, Table I.

VI TEST PROCEDURES AND METHOD OF HANDLING DATA

As previously stated in Section III, one purpose of this experiment was to obtain yarn width measurements for use in calculating the percent open area by equation (1).

Another purpose was to detect any change in the cloth area under test due to pressure differential on the specimen.

In order to obtain the necessary data for the calculation of percent open area of the cloth at rest, and dynamically, the apparatus was assembled as shown in Figure 4.

Each of the twenty-eight (28) different samples was tested for air permeability at the following air pressure differentials:

0 inches of water

2 inches of water

5 inches of water

10 inches of water

18 inches of water

These test data are shown in Appendix I, Table II.

One photograph was made simultaneously with the determination of air permeability at each of the above pressure differentials. This was accomplished on all twenty-eight (28) samples of cloth and gave a total of 140 photographs for study and measurement of warp and filling yarn widths. The finished photographs were standard letter size and had a magnification of 88 diameters. One complete set of these photographs are included in Appendix II for clarity. In order to decrease the bulk of this report the other four (4) sets have been excluded. However, the data on yarn width taken from these prints are included herein.

The 140 photographs were evaluated for fabric thread count and warp and filling yarn widths. These values were substituted in equation (1) and the percent open area determined. These data are shown in Appendix I, Tables III and IV. The width measurement and thread count measurement were made with a plastic scale reproduced from a photograph made in exactly the same manner in which the fabric prints were made. Its magnification was the same (88 diameters). A photograph of this scale is shown in Appendix II. The smallest graduation of the original scale was equal to 0.001 inches, while the smallest graduation of the reproduced plastic scale was equivalent to 0.088 inches.

The transparent plastic scale was superimposed on the photograph and the average yarn widths and thread counts determined from numerous measurements.

The calculated percent open area values were plotted against air permeability at the various pressure differentials. These data are shown in Appendix I, Figures 5, 6, 7, and 8.

The effects of twist in the warp and filling yarns, and the effects of calendering, on air permeability are shown in Appendix I, Figure 9.

VII. DISCUSSION

The experimental data shown in Figures 5, 6, 7 and 8 are obviously scattered about a visually determined curve. This may be due in part to the fact that only a relatively small portion of the cloth area through which the air permeability was measured, is shown in the photographs. Complete accuracy in determining thread count was not possible because of natural fabric variance and the non-uniformity of sley induced by the grouping of warp yarns in the reed.

It should be borne in mind that other factors, such as yarn tension, crimp and finishing techniques, will each have some effect on the fabric open area. This has been an attempt to: (1) Measure the sum of all of these various effects, including yarn twist, in terms of the final differences between the total fabric area and its open area and; (2) to correlate these results with air flow at several air pressure differentials.

VIII. CONCLUSIONS

1. This study indicates strongly that the percent open area in the cloth tested, has a linear relationship with air permeability, at least at the pressure differentials studied.

2. The variation of yarn twist in either the warp or filling yarns, has a pronounced effect on the open area and air permeability of nylon parachute cloth.

3. It is believed that some part of the objective of this study has been attained in that the mechanics of air flow through cloth has been somewhat simplified. However, much is still to be done in the way of establishing clear cut design data on yarn width constants and effects of biaxial loading on open area and air permeability of nylon parachute types of fabrics.

It can be seen from Table IV that the maximum cloth area available for air flow is approximately 20 percent at the pressure differentials used. This is considerably more than would be permitted for this type of parachute cloth since strength decreases with addition of twist in excess of 15 turns per inch and weight of cloth increases also with addition of twist.

4. There is some indication from these data that fabric open area increases with pressure differential. It is anticipated that this will be investigated in future work at Wright Air Development Center.

APPENDIX I TEST ARRANGEMENT AND TABULATION OF PHYSICAL DATA

TABLE I

TEST RESULTS OF FINISHED NYLON CLOTH

Sample	Filling Twist Turns/inch	*Air Permeability $ft^3/min/ft^2$	Warp Ends/inch	Filling Picks/inch
7C1/2	1.15	27	129	77
7C2 1/2	3.45	32	129	76
7C5	6.15	53	129	77
7C7	7.95	70	129	76
7C15	16.85	181	128	76
7C20	23.50	271	128	77
7C35	39.60	395	127	75
7N1/2	1.05	110	128	77
7N2 1/2	3.40	142	127	76
7N5	6.25	186	127	77
7N7	8.00	221	127	76
7N15	16.60	367	124	76
7N20	23.30	465	124	76
7N35	39.40	610	123	74
10C1/2	1.10	25	128	76
10C2 1/2	3.45	37	129	76
10C5	6.60	66	130	76
10C7	7.70	81	130	76
10C15	16.45	218	126	76
10C20	23.00	300	128	76
10C35	39.50	457	128	75

TABLE I TEST RESULTS OF FINISHED NYLON CLOTH (cont'd)

Sample	Filling Twist, Turns/inch	*Air Permeability, $ft^3/min/ft^2$	Warp Ends/inch	Filling Picks/inch
10N1/2	1.10	112	128	76
10N2 1/2	3.30	161	128	76
10N5	6.25	206	128	76
10N7	7.60	245	128	76
10N15	16.80	407	126	76
10N20	23.10	545	125	76
10N35	39.50	692	124	75

Above values are averages of three (3) tests.

* Taken at a pressure differential of 0.5 inch of water

TABLE II

PRESSURE, PERMEABILITY AND FILM DATA

Sample Number	Air Permeability ($ft^3/min/ft^2$) @ Pressure Differential (in. of water)					Orifice Diameter, mm.	Film Roll Number	Film Exposure Numbers
	0	2	5	10	18			
7C1/2	0	75	151	265	397	8.15	2	1 to 5
7C2 1/2	0	102	207	356	511	8.15	2	6 to 10
7C5	0	158	302	492	725	8.15	2	11 to 15
7C7	0	180	342	539	791	8.15	2	16 to 20
7C15	0	434	772	1185	1708	11.00	3	1 to 5
7C20	0	890	1253	1936	2667	16.00	3	6 to 7A to 10
7C35	0	1073	1711	2572	3600	16.00	3	11 to 15
7N1/2	0	237	442	690	969	8.15	1	1 to 5
7N2 1/2	0	327	594	939	1322	11.00	4	11 to 15

TABLE II PRESSURE, PERMEABILITY AND FILM DATA (Cont'd)

Sample Number	Air Permeability (ft^3/min/ft^2) at Pressure Differential (in. of water)					Orifice Diameter, mm.	Film Roll Number	Film Exposure Numbers
	0	2	5	10	18			
7N5	0	469	838	1265	1830	11.00	4	16 to 20
7N7	0	833	1097	1633	2299	16.00	4	6 to 10
7N15	0	1049	1657	2477	3416	16.00	4	1 to 5
7N20	0	1193	1936	2931	4048	16.00	3	21 to 25
7N35	0	1550	2542	3760	NR	16.00	3	16 to 20
10C1/2	0	95	183	300	463	8.15	6	1 to 5
10C2 1/2	0	131	264	442	655	8.15	5	21 to 25
10C5	0	183	356	576	843	8.15	5	16 to 20
10C7	0	143	351	594	879	11.00	5	11 to 15
10C15	0	564	980	1485	2171	11.00	5	6 to 10
10C20	0	1133	1372	2026	2827	16.00	5	1 to 5
10C35	0	1193	1984	2768	4048	16.00	4	21 to 25
10N1/2	0	300	549	845	1194	8.15	7	11 to 15
10N2 1/2	0	351	701	1096	1540	11.00	7	6 to 10
10N5	0	535	980	1461	2124	11.00	7	1 to 5
10N7	0	833	1193	1752	2477	16.00	6	21 to 25
10N15	0	1073	1847	2732	3802	16.00	6	16 to 20
10N20	0	1313	2257	3368	NR	16.00	6	11 to 15
10N35	0	1711	2827	4182	NR	16.00	6	6 to 10

NR = No Reading

TABLE III

THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS

SAMPLES UNDER NO PRESSURE DIFFERENTIAL

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
7C1/2	134.6	77.8	.0058	.0111
7C2 1/2	132.7	79.1	.0053	.0123
7C5	134.2	77.7	.0058	.0120
7C7	130	80.8	.0057	.0114
7C15	131.3	81.3	.0059	.0100
7C20	129.2	80.4	.0056	.0081
7C35	132.1	76.3	.0061	.0069
7N1/2	133.3	75.0	.0049	.0118
7N2 1/2	130	78.4	.0049	.0120
7N5	131.4	77.7	.0047	.0111
7N7	136.1	78.8	.0046	.0107
7N15	126.5	77.7	.0048	.0081
7N20	126.9	79.8	.0048	.0073
7N35	125.6	81.3	.0051	.0049
10C1/2	130.4	75.8	.0059	.0138
10C2 1/2	133.1	77.5	.0061	.0124
10C5	132.3	75.9	.0059	.0128
10C7	130	77.5	.0060	.0121
10C15	128.2	75.7	.0054	.0098
10C20	130.8	78.3	.0060	.0083
10C35	131.5	75.3	.0055	.0067

TABLE III THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS (Cont'd)

SAMPLES UNDER NO PRESSURE DIFFERENTIAL (Cont'd)

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
10N1/2	128.8	76.5	.0047	.0120
10N2 1/2	130.7	76.7	.0052	.0110
10N5	132.1	76.7	.0050	.0104
10N7	132.3	76.3	.0049	.0100
10N15	126.7	76.0	.0046	.0090
10N20	127.3	76.5	.0046	.0078
10N35	127.1	75.4	.0054	.0051

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 2 INCHES OF WATER

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
7C1/2	134.8	77.3	.0059	.0127
7C2 1/2	132.3	78.8	.0052	.0122
7C5	135.2	78.0	.0058	.0122
7C7	131.3	80.9	.0053	.0113
7C15	131.3	81.5	.0056	.0104
7C20	129.5	80.7	.0056	.0081
7C35	132.0	76.3	.0054	.0070
7N1/2	134.6	75.0	.0051	.0115
7N2 1/2	129.8	77.9	.0048	.0121
7N5	131.0	77.5	.0047	.0115
7N7	136.3	78.8	.0046	.0104
7N15	127.3	77.5	.0050	.0083
7N20	126.9	80.2	.0047	.0077
7N35	125.0	81.0	.0055	.0048

TABLE III THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS (Cont'd)

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 2 INCHES OF WATER (Cont'd)

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
10C1/2	130.3	75.8	.0059	.0136
10C2 1/2	133.2	77.0	.0058	.0123
10C5	132.1	75.0	.0057	.0121
10C7	130.0	76.5	.0059	.0118
10C15	128.3	76.9	.0050	.0094
10C20	130.9	78.3	.0056	.0081
10C35	130.1	75.0	.0056	.0064
10N1/2	128.8	76.3	.0051	.0123
10N2 1/2	130.4	76.9	.0051	.0112
10N5	132.1	77.5	.0048	.0105
10N7	132.0	75.8	.0048	.0095
10N15	127.9	76.3	.0048	.0087
10N20	128.5	77.1	.0047	.0077
10N35	127.5	75.4	.0052	.0051

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 5 INCHES OF WATER

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
7C1/2	133.8	77.5	.0058	.0126
7C2 1/2	132.7	78.9	.0051	.0122
7C5	132.0	77.2	.0057	.0119
7C7	129.4	80.5	.0051	.0115
7C15	130.8	81.3	.0053	.0101
7C20	128.3	80.7	.0057	.0084
7C35	131.4	75.7	.0056	.0070

TABLE III THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS (Cont'd)

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 5 INCHES OF WATER (Cont'd)

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
7N1/2	134.8	75.0	.0054	.0114
7N2 1/2	130.0	78.6	.0048	.0120
7N5	130.2	77.1	.0048	.0113
7N7	136.5	80.0	.0046	.0104
7N15	125.2	77.3	.0051	.0083
7N20	126.7	81.1	.0048	.0077
7N35	124.6	80.5	.0057	.0048
10C1/2	129.6	75.3	.0058	.0136
10C2 1/2	132.1	76.8	.0057	.0123
10C5	133.4	75.6	.0057	.0121
10C7	129.1	76.6	.0060	.0117
10C15	127.1	75.5	.0050	.0096
10C20	130.2	77.9	.0057	.0079
10C35	129.4	75.0	.0057	.0064
10N1/2	129.2	76.3	.0049	.0125
10N2 1/2	130.2	76.3	.0052	.0110
10N5	131.5	75.9	.0048	.0103
10N7	131.8	75.6	.0048	.0096
10N15	126.5	75.6	.0046	.0084
10N20	127.5	76.5	.0047	.0077
10N35	127.3	75.7	.0051	.0051

TABLE III THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS (Cont'd)

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 10 INCHES OF WATER

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
7C1/2	134.2	77.5	.0059	.0127
7C2 1/2	132.8	79.5	.0051	.0121
7C5	130.6	77.4	.0062	.0122
7C7	129.8	80.0	.0053	.0115
7C15	131.0	81.1	.0053	.0101
7C20	130.4	82.5	.0059	.0080
7C35	130.9	75.8	.0057	.0071
7N1/2	132.3	75.0	.0052	.0115
7N2 1/2	128.8	78.0	.0046	.0120
7N5	130.0	77.3	.0048	.0112
7N7	136.2	78.9	.0046	.0106
7N15	125.4	76.7	.0052	.0080
7N20	126.7	80.6	.0048	.0076
7N35	124.2	80.2	.0057	.0049
10C1/2	128.5	75.4	.0058	.0135
10C2 1/2	132.0	76.5	.0059	.0123
10C5	130.9	75.2	.0059	.0121
10C7	129.4	76.3	.0061	.0117
10C15	127.7	75.5	.0053	.0094
10C20	130.7	77.6	.0058	.0082
10C35	128.9	75.0	.0057	.0066

TABLE III THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS (Cont'd)

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 10 INCHES OF WATER (Cont'd)

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
10N1/2	129.0	76.3	.0052	.0126
10N2 1/2	130.0	76.5	.0055	.0113
10N5	131.0	76.9	.0050	.0109
10N7	132.3	75.6	.0052	.0102
10N15	126.3	76.0	.0048	.0089
10N20	127.9	76.8	.0048	.0081
10N35	126.8	75.6	.0055	.0055

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 18 INCHES OF WATER

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
7C1/2	134.0	76.4	.0060	.0130
7C2 1/2	130.7	78.9	.0052	.0125
7C5	131.7	76.7	.0061	.0121
7C7	129.1	80.5	.0055	.0117
7C15	130.8	81.3	.0055	.0103
7C20	129.7	82.3	.0061	.0083
7C35	130.4	75.8	.0058	.0073
7N1/2	134.4	75.0	.0052	.0116
7N2 1/2	129.5	77.9	.0046	.0117
7N5	128.2	76.3	.0047	.0112
7N7	135.4	78.4	.0047	.0108
7N15	125.0	77.3	.0055	.0081
7N20	125.8	80.4	.0047	.0077
7N35	124.5	80.7	.0060	.0052

TABLE III THREAD COUNT AND YARN WIDTH MEASUREMENTS FROM PRINTS (Cont d)

SAMPLES UNDER PRESSURE DIFFERENTIAL OF 18 INCHES OF WATER (Cont'd)

Sample Number	Ends Per Inch	Picks Per Inch	Average Warp Yarn Width (in.)	Average Fill Yarn Width (in.)
10C1/2	126.9	75.4	.0057	.0135
10C2 1/2	131.0	76.3	.0060	.0124
10C5	131.3	75.2	.0059	.0123
10C7	128.3	77.0	.0064	.0120
10C15	128.2	75.6	.0054	.0100
10C20	130.2	78.8	.0062	.0086
10C35	129.1	75.0	.0059	.0070
10N1/2	128.4	75.8	.0051	.0123
10N2 1/2	129.4	75.8	.0053	.0115
10N5	130.5	75.8	.0050	.0112
10N7	130.6	75.4	.0049	.0105
10N15	126.3	75.2	.0047	.0088
10N20	126.8	76.6	.0048	.0081
10N35	126.5	75.4	.0056	.0055

TABLE IV

PERCENT OPEN AREA OF CLOTH VERSUS PRESSURE (INCHES OF WATER) AND AIR PERMEABILITY

($FT^3/MIN/FT^2$)

Sample Number	0" Pressure Differential		2" Pressure Differential		5" Pressure Differential		10" Pressure Differential		18" Pressure Differential	
	Air Perm.	Open Area,%	Air Perm	Open Area,%	Air Perm	Open Area,%	Air Perm	Open Area,%	Air Perm	Open Area,%
7C1/2	0	2.99	75	.37	151	.53	265	.33	397	.13
7C2 1/2	0	.80	102	1.21	207	1.21	356	1.23	511	.44
7C5	0	1.50	158	1.04	302	2.01	492	1.06	725	1.41
7C7	0	2.04	180	2.61	342	2.52	539	2.50	791	1.69
7C15	0	4.21	434	4.03	772	9.49	1185	5.53	1708	4.56
7C20	0	9.64	890	9.52	1253	8.65	1936	7.84	2667	6.62
7C35	0	9.19	1073	13.38	1711	12.42	2572	11.72	3600	10.88
7N1/2	0	3.99	237	4.31	442	3.94	690	4.29	9.69	3.91
7N2 1/2	0	2.15	327	2.16	594	2.14	939	2.61	1322	3.58
7N5	0	5.26	469	4.18	838	4.83	1265	5.05	1830	5.78
7N7	0	5.86	833	6.73	1097	6.25	1633	6.11	2299	5.57
7N15	0	14.56	1049	12.97	1657	12.96	2477	13.44	3416	11.68
7N20	0	16.32	1193	15.43	1936	14.71	2931	15.88	4048	15.57
7N35	0	21.62	1550	19.10	2542	17.77	3760	17.73	NR	NR
10C1/2	0	-1.06*	95	-.71*	183	-.60*	300	-.54*	463	-.50*
10C2 1/2	0	.73	131	1.20	264	1.37	442	1.31	655	1.15
10C5	0	.62	183	2.28	356	2.04	576	2.05	843	1.69
10C7	0	1.37	143	2.27	351	2.34	594	2.26	879	1.36
10C15	0	7.94	564	9.93	980	10.03	1485	9.38	2171	7.51

TABLE IV

PERCENT OPEN AREA OF CLOTH VERSUS PRESSURE (INCHES OF WATER) AND AIR PERMEABILITY ($FT^3/MIN/FT^2$) (Cont'd)

Sample Number	0" Pressure Differential		2" Pressure Differential		5" Pressure Differential		10" Pressure Differential		18" Pressure Differential	
	Air Perm	Open Area,%	Air Perm	Open Area,%	Air Perm	Open Area,%	Air Perm	Open Area,%	Air Perm	Open Area,%
10C20	0	7.53	1133	9.76	1372	9.92	2026	8.80	2827	6.21
10C35	0	13.71	1193	14.11	1984	13.65	2768	13.40	4048	11.32
10N1/2	0	3.24	300	2.11	549	1.70	845	1.27	1194	2.33
10N2 1/2	0	5.01	351	4.65	701	5.19	1096	3.86	1540	4.03
10N5	0	6.87	535	6.71	980	8.05	1461	5.58	2124	5.25
10N7	0	8.34	833	10.26	1193	10.17	1752	7.14	2477	7.50
10N15	0	13.18	1073	12.98	1847	15.26	2732	12.74	3802	13.75
10N20	0	16.71	1313	16.09	2257	16.47	3368	14.59	NR	NR
10N35	0	19.30	1711	20.74	2827	21.53	4182	17.68	NR	NR

NR = No Reading

* - Indicates a cover factor greater than unity or no open area. This of course is not the case.

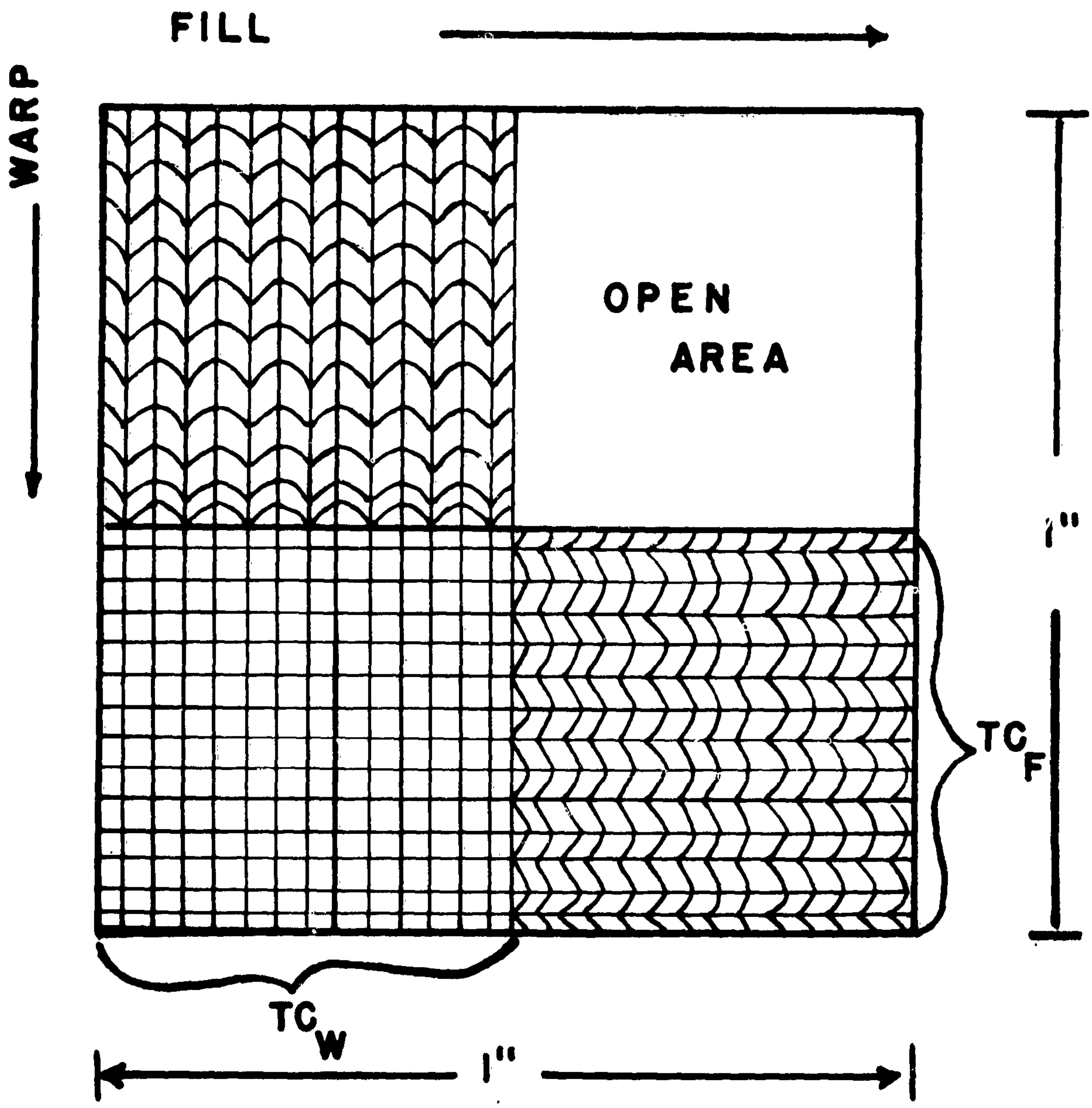

FIG. - 1 SCHEMATIC OF OPEN AREA ANALOGY

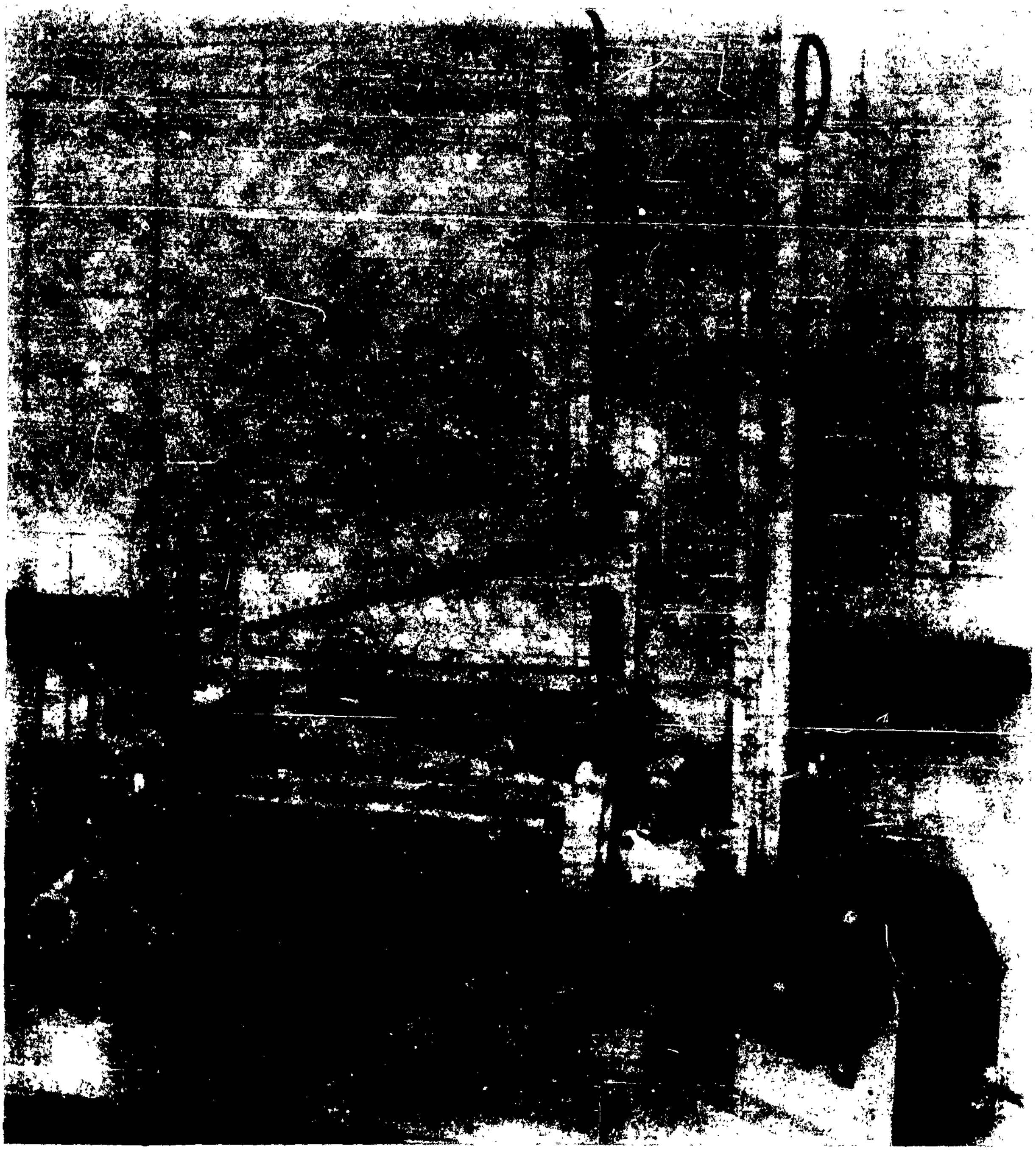

Figure 2

VIEW OF AIR PERMEABILITY APPARATUS

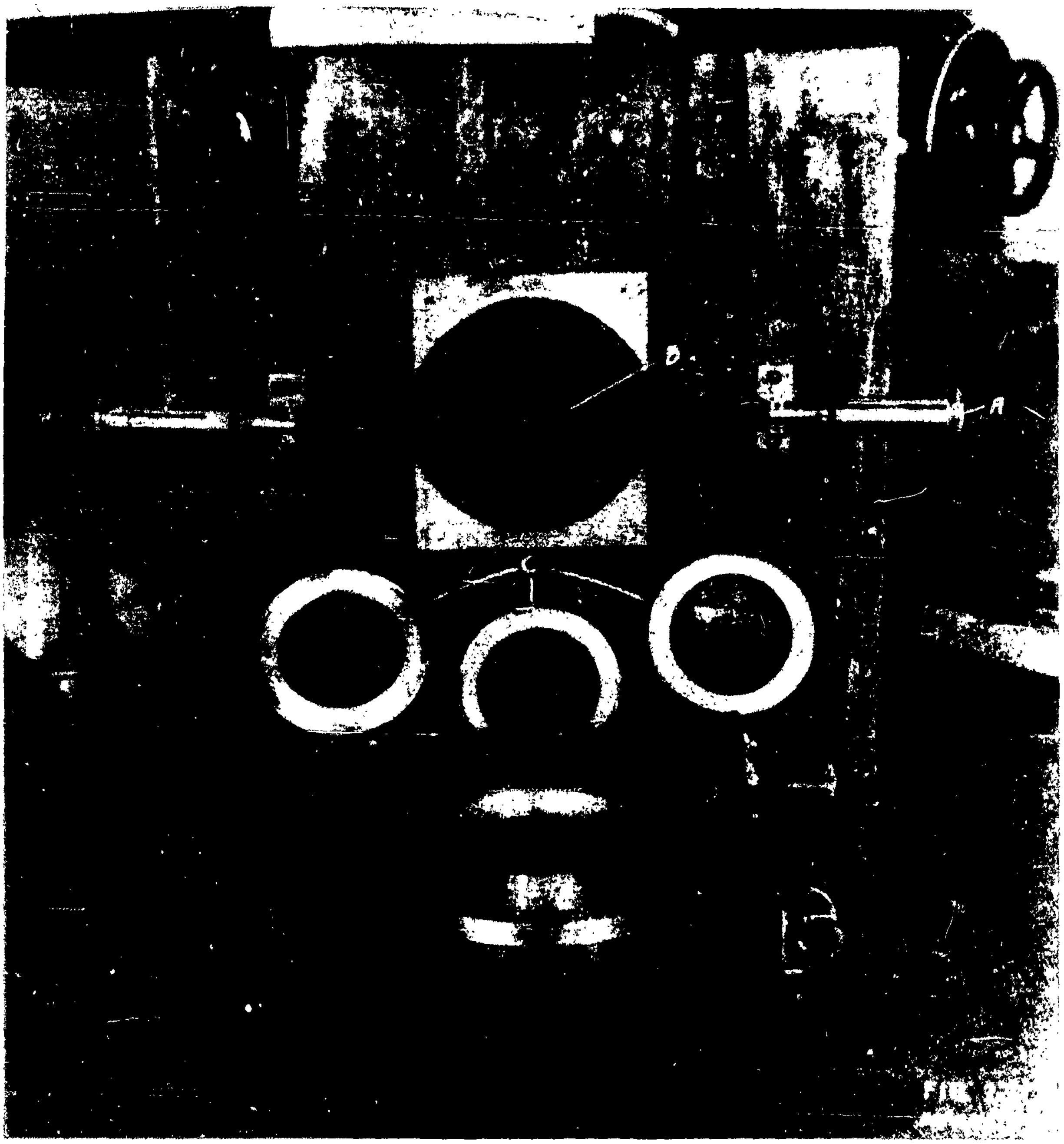

Figure 3

VIEW OF AIR PERMEABILITY APPARATUS

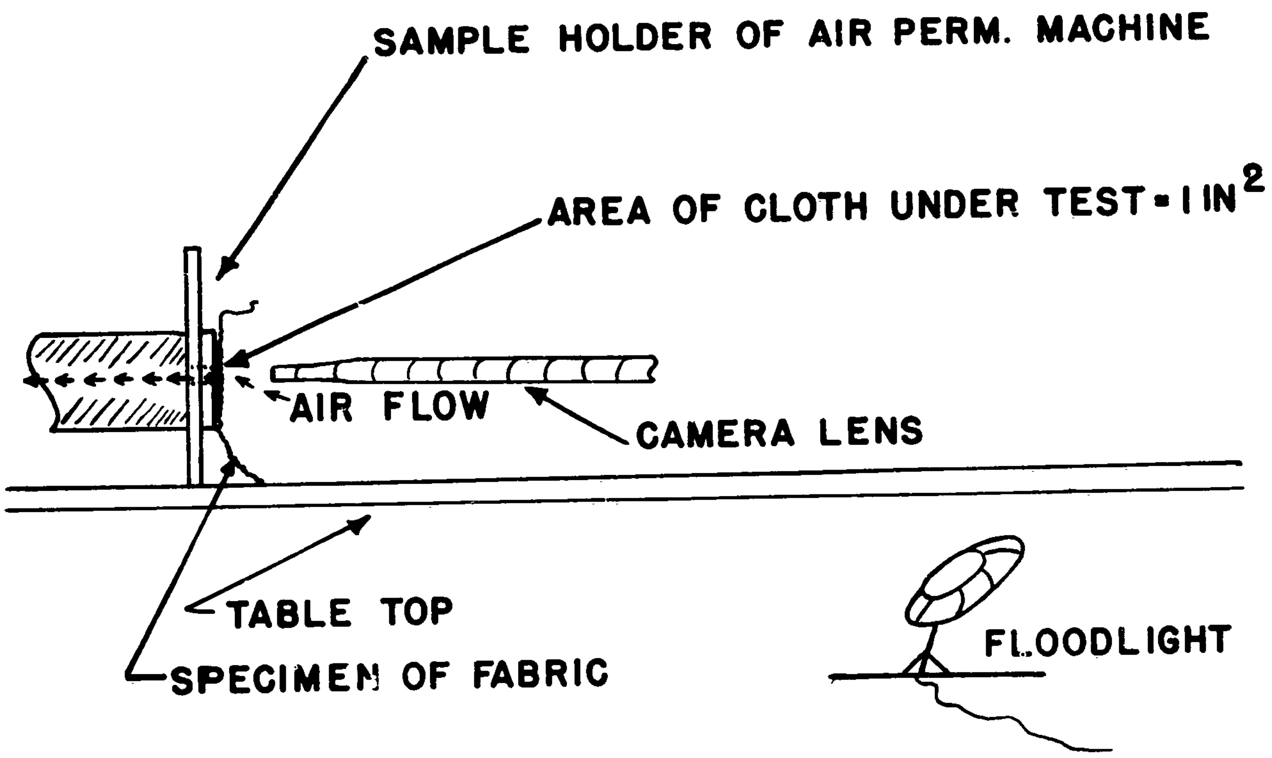

Figure 4

PHOTOGRAPHIC ARRANGEMENT

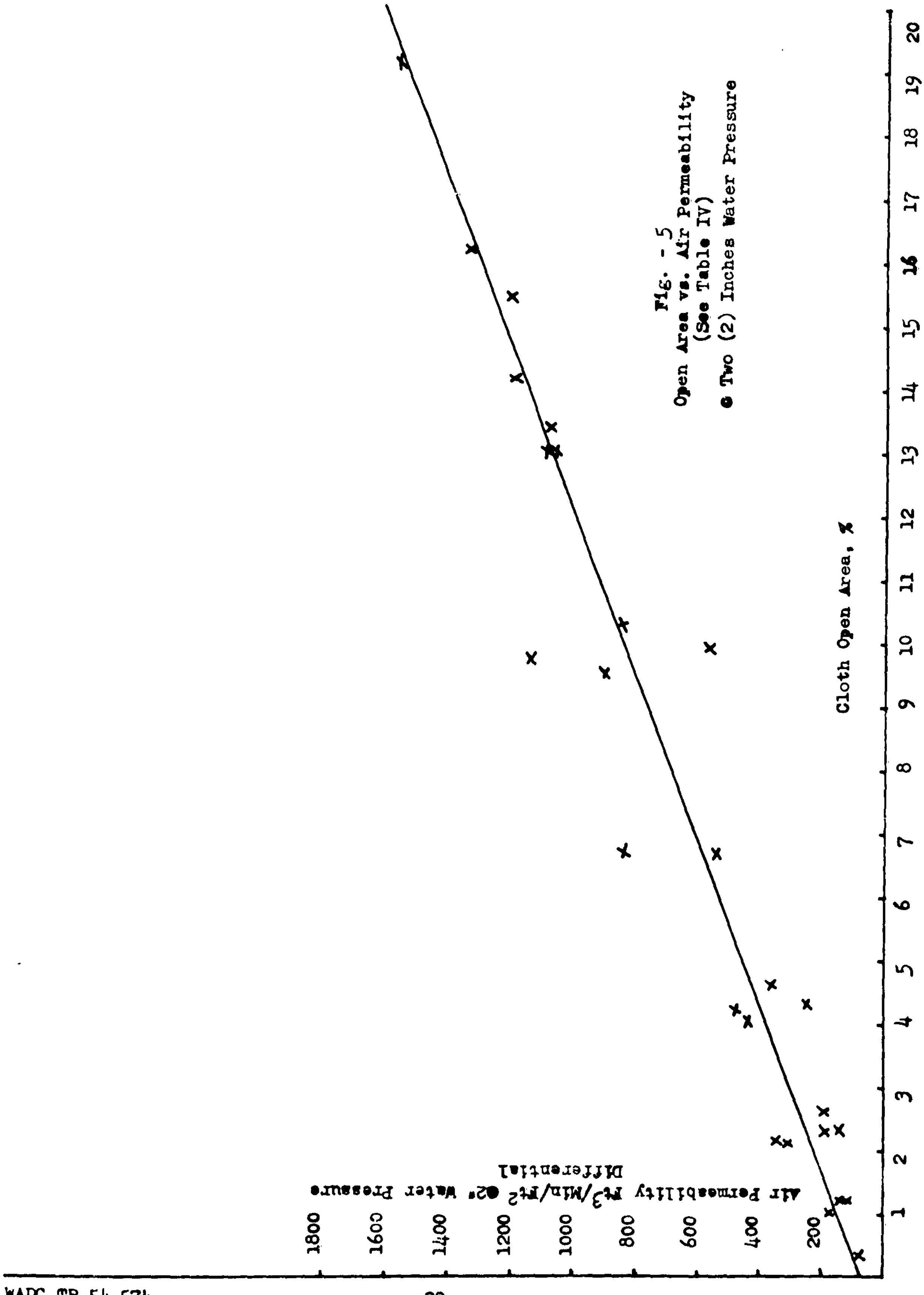

Fig. - 5
Open Area vs. Air Permeability
(See Table IV)
@ Two (2) Inches Water Pressure

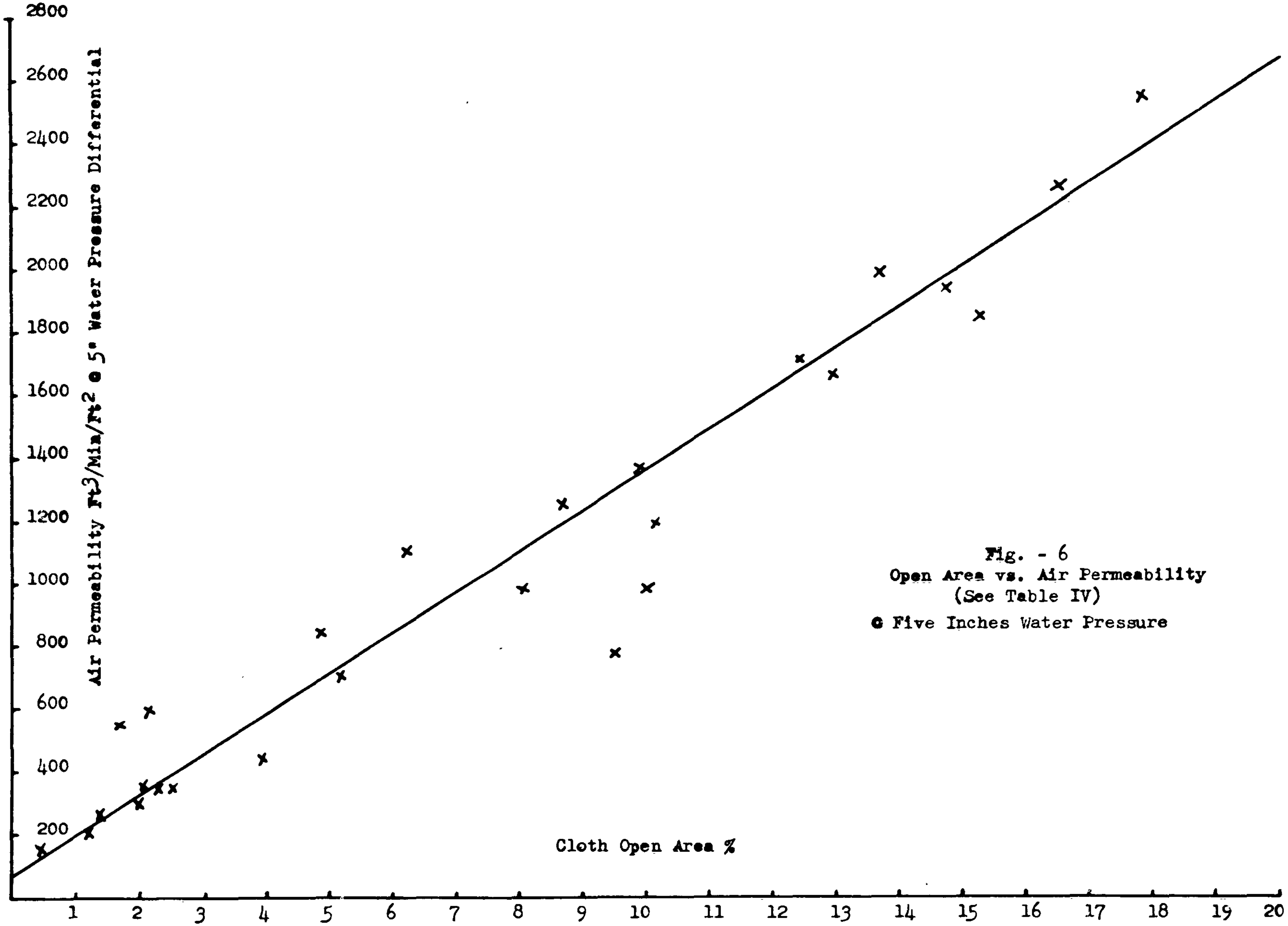

Fig. - 6
Open Area vs. Air Permeability
(See Table IV)
@ Five Inches Water Pressure

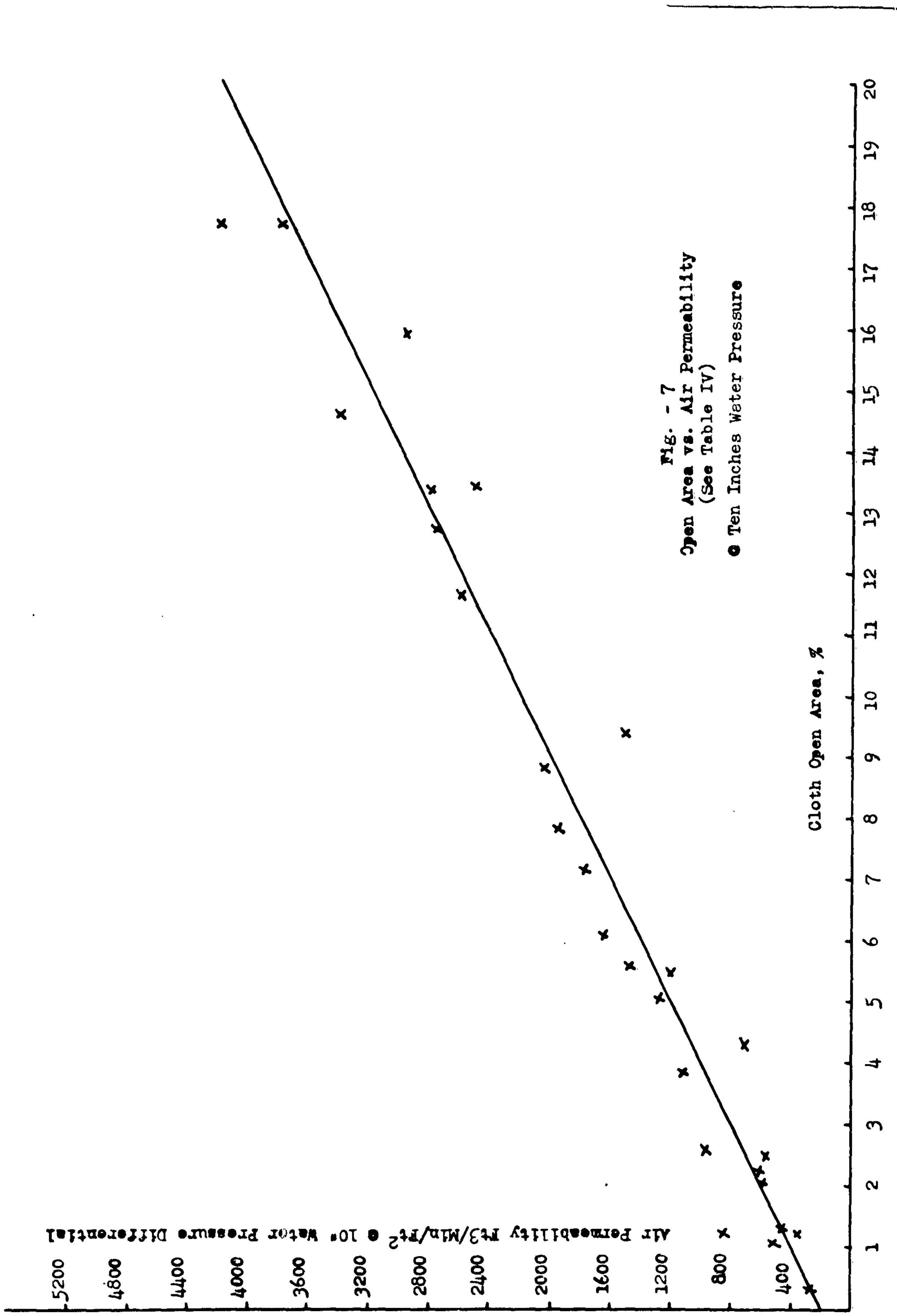

Fig. - 7
Open Area vs. Air Permeability
(See Table IV)

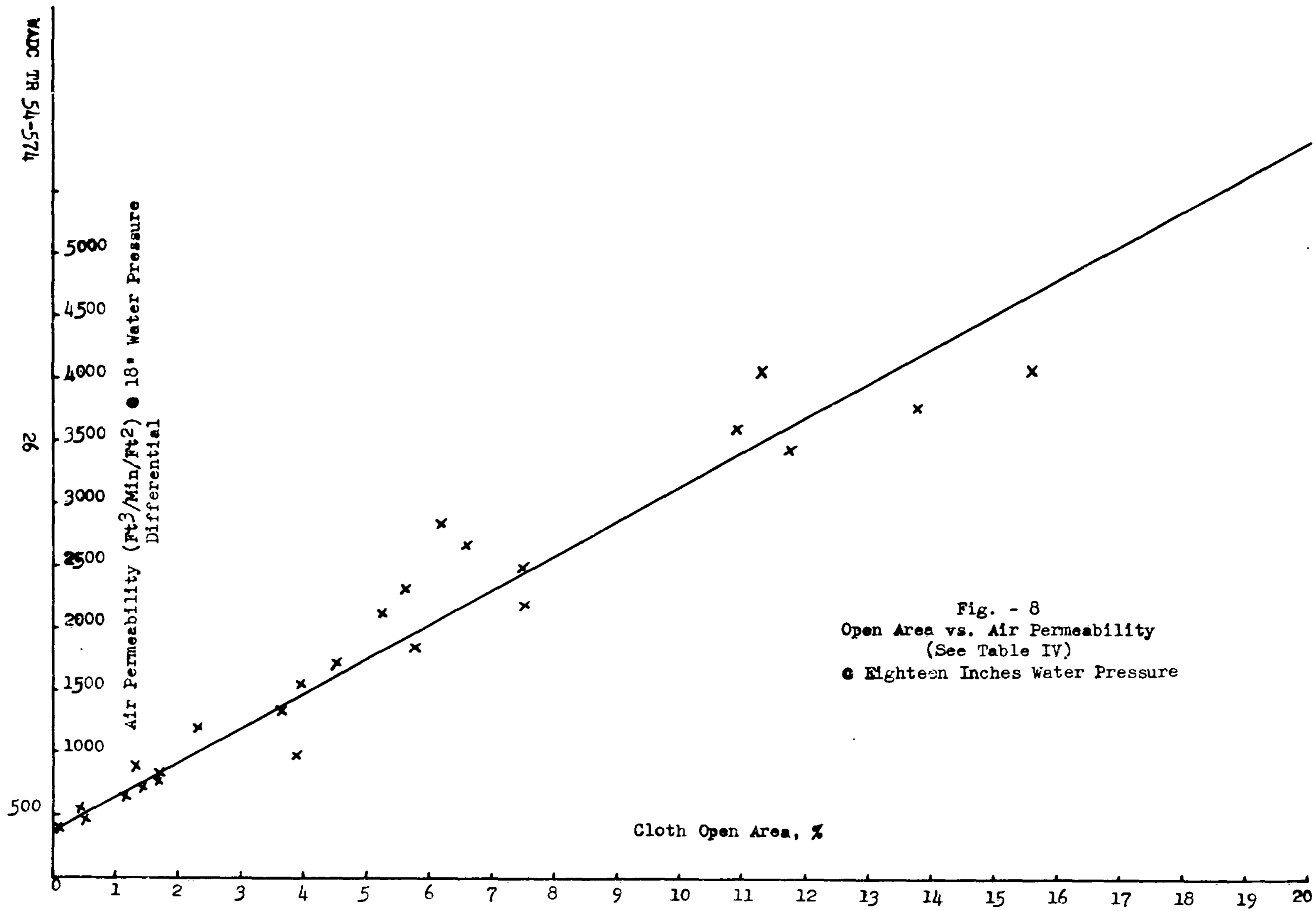

Fig. - 8
Open Area vs. Air Permeability
(See Table IV)
@ Eighteen Inches Water Pressure

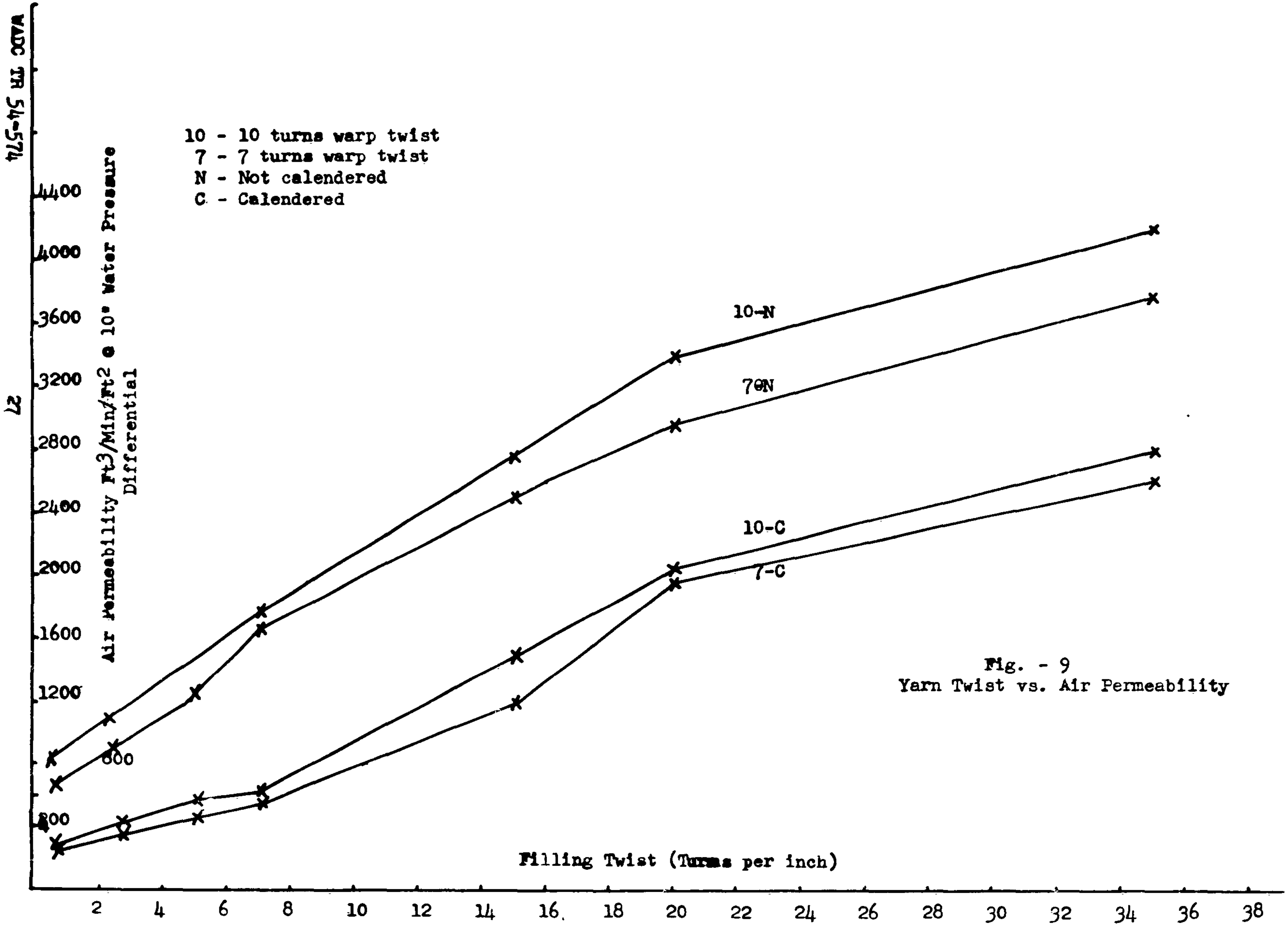

Fig. - 9
Yarn Twist vs. Air Permeability

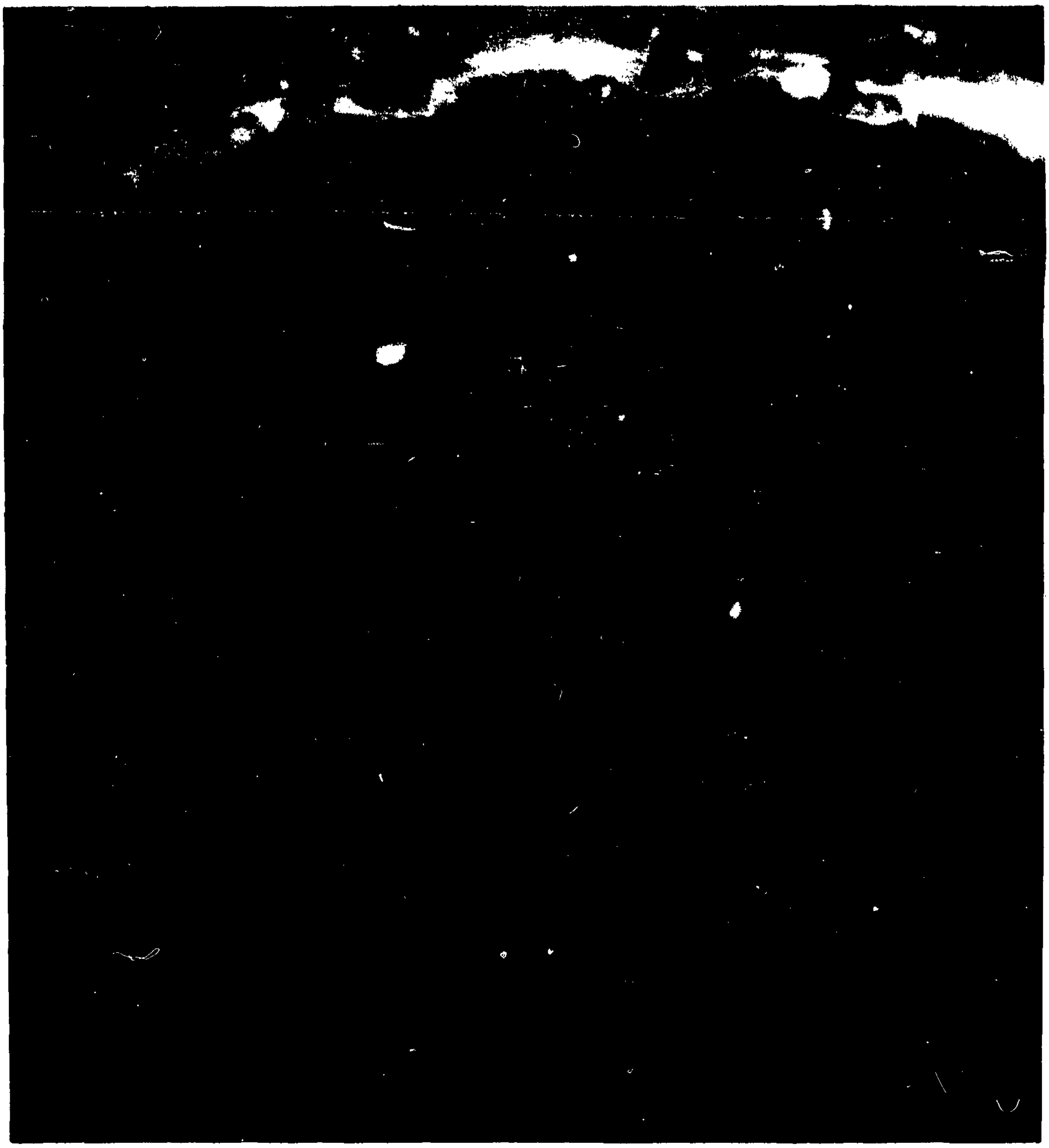

Figure 10

PHOTOGRAPH OF YARN WIDTH MEASURING DEVICE

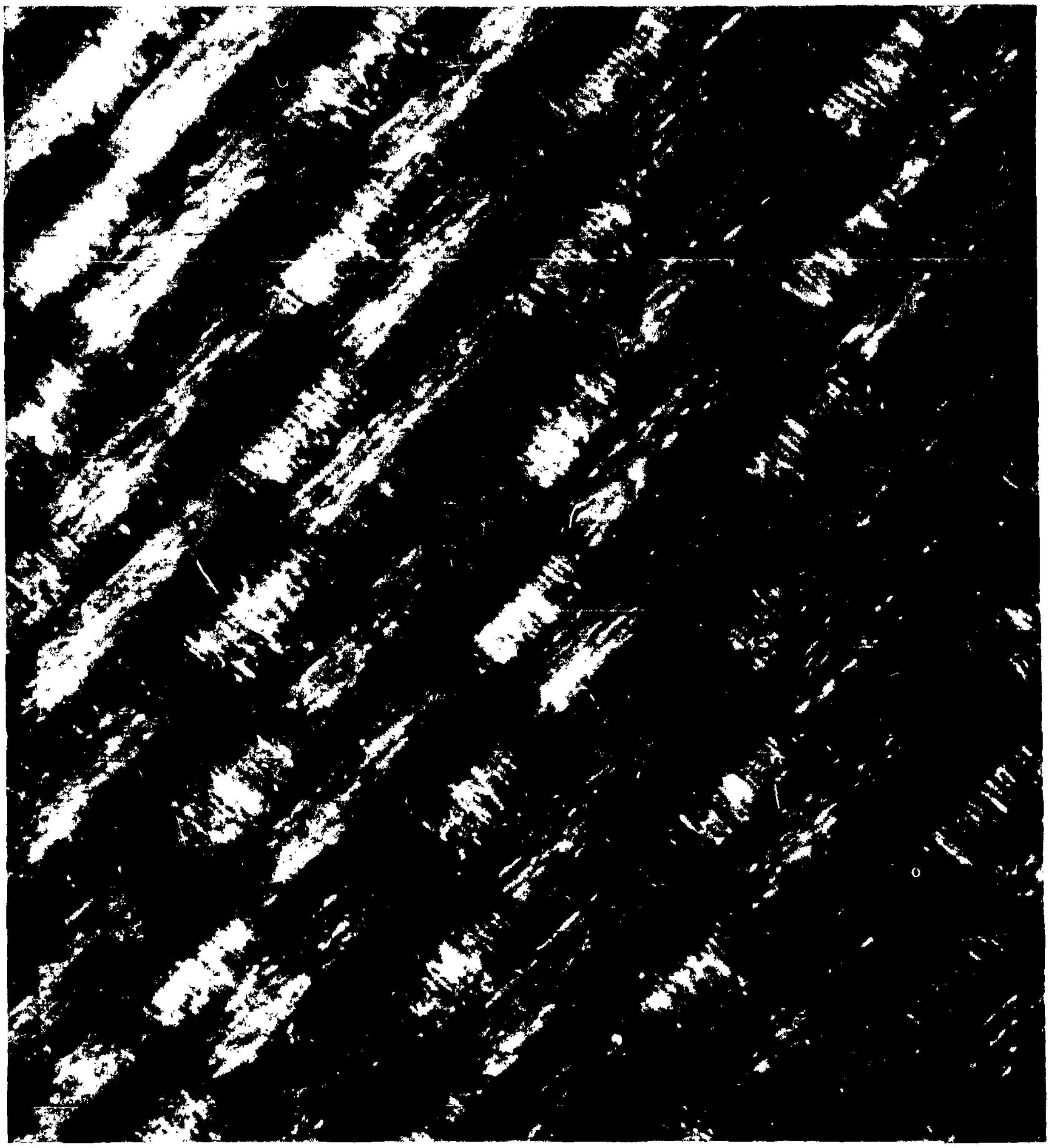

Figure 11

PHOTOGRAPH OF SAMPLE 7C 2 1/2 @ TEN (10) INCHES WATER PRESSURE

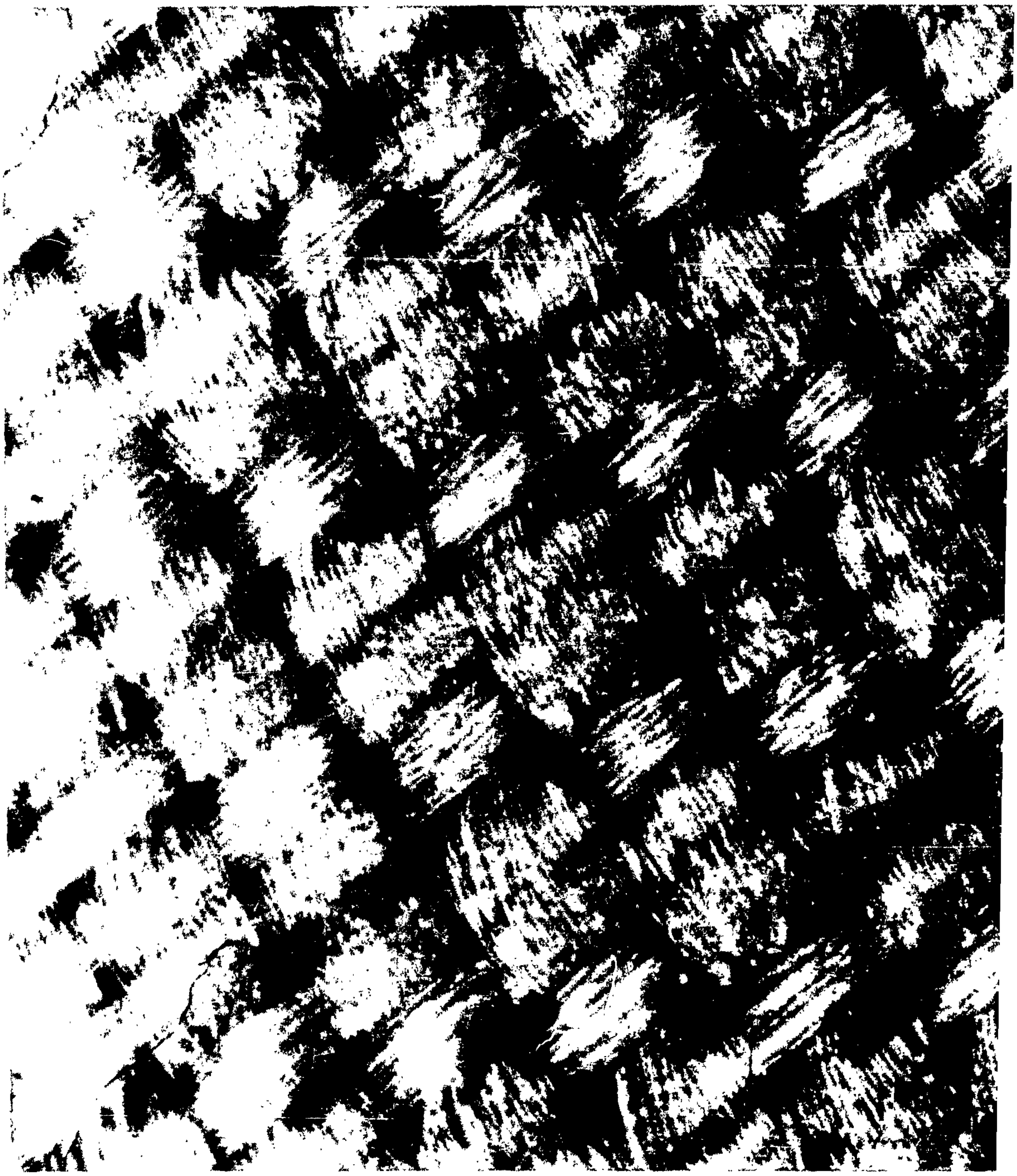

Figure 12

PHOTOGRAPH OF SAMPLE 7C 5 @ TEN (10) INCHES WATER PRESSURE

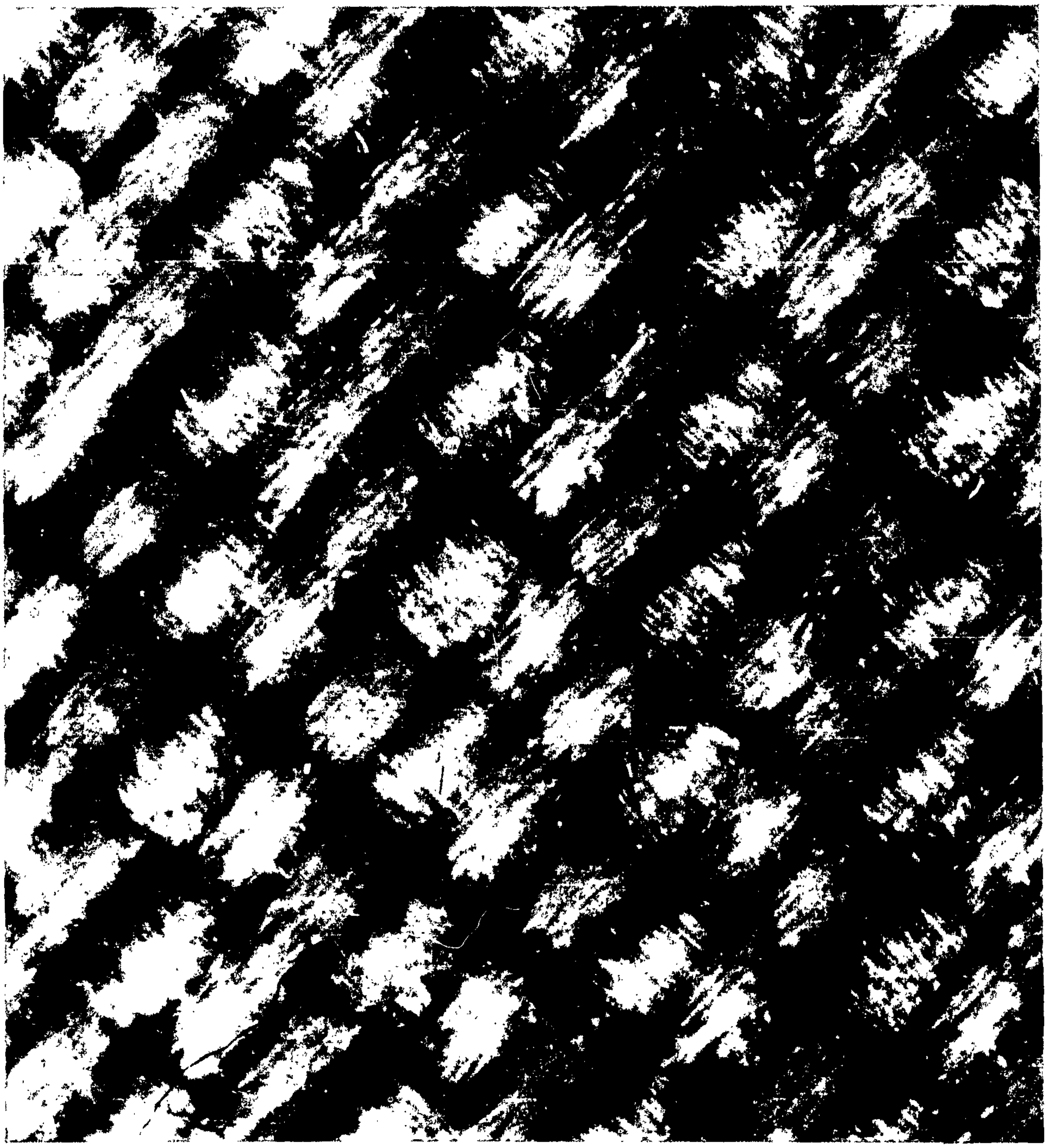

Figure 13

PHOTOGRAPH OF SAMPLE 7C 7 @ TEN (10) INCHES WATER PRESSURE

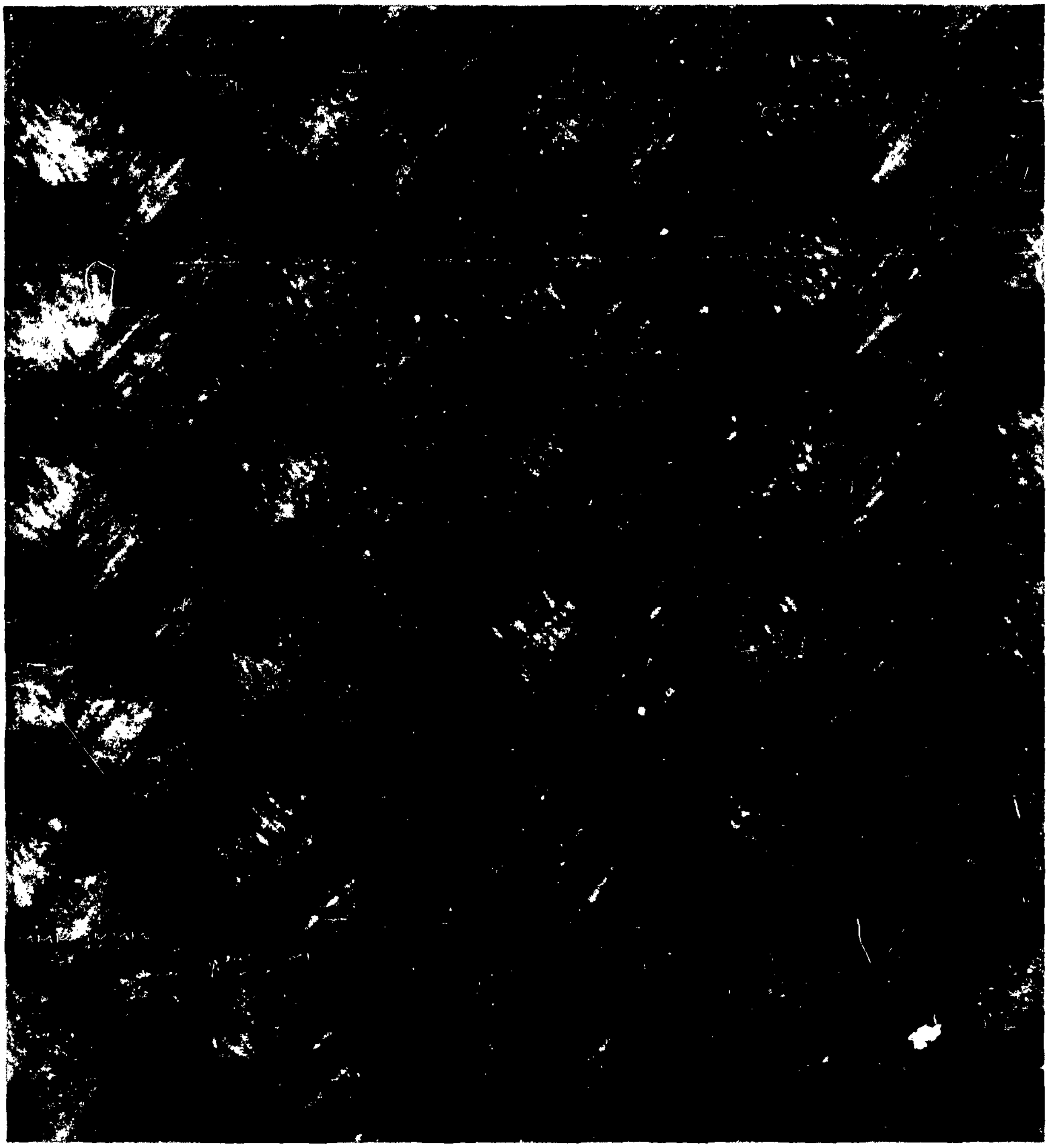

Figure 14

PHOTOGRAPH OF SAMPLE 7C 15 @ TEN (10) INCHES WATER PRESSURE

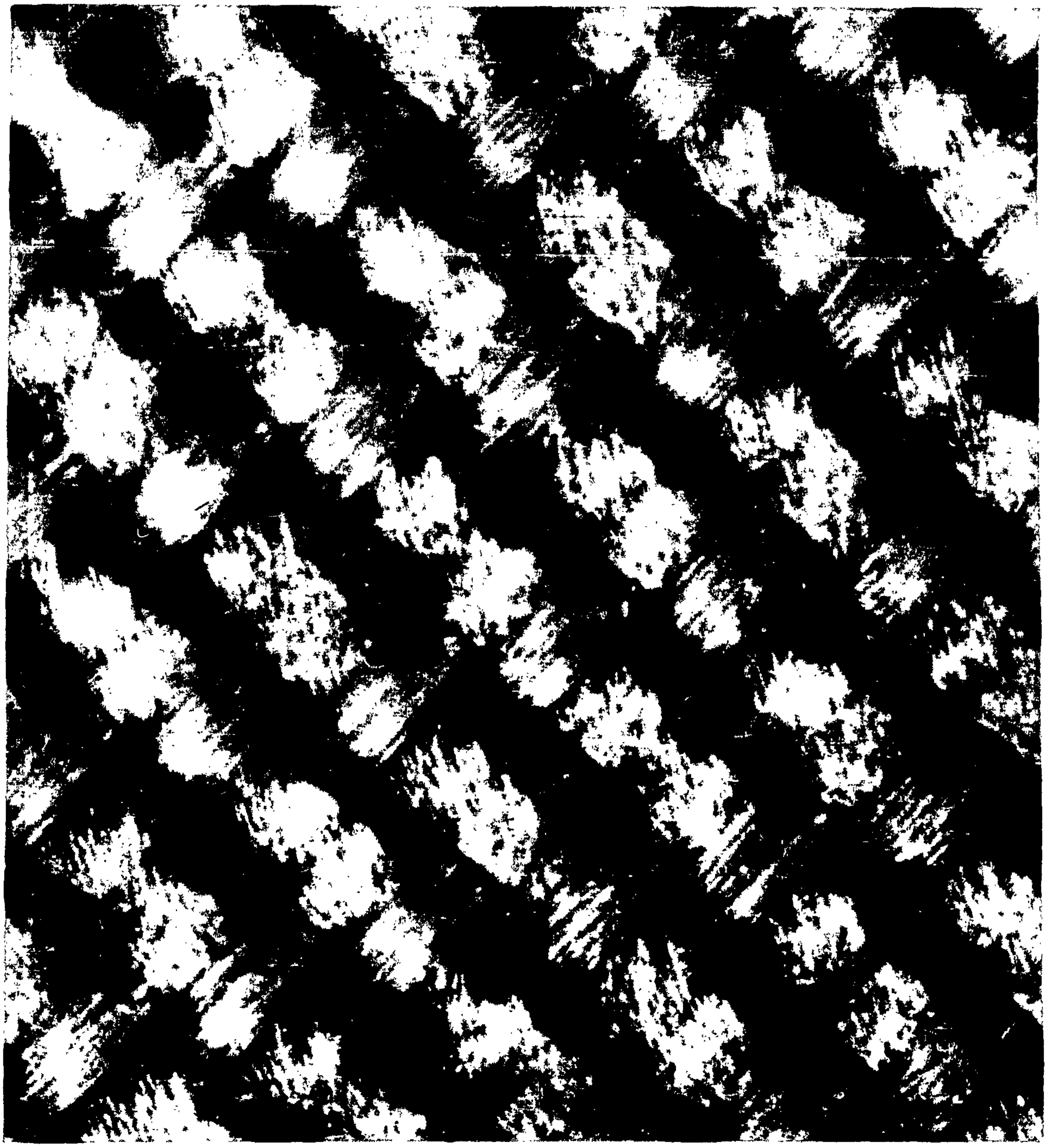

Figure 15

PHOTOGRAPH OF SAMPLE 7C 20 @ TEN (10) INCHES WATER PRESSURE

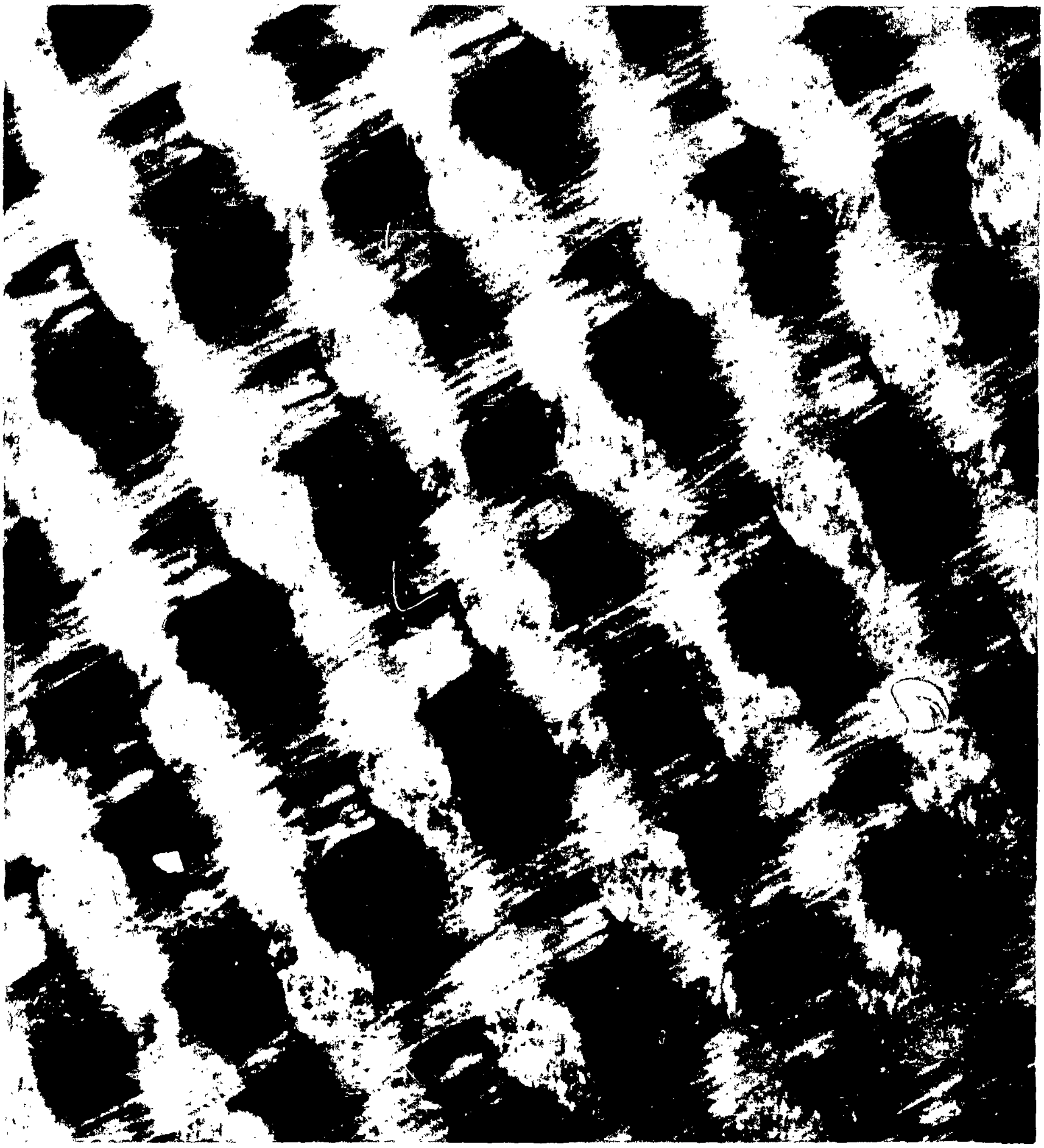

Figure 16

PHOTOGRAPH OF SAMPLE 7C 35 @ TEN (10) INCHES WATER PRESSURE

Figure 17

PHOTOGRAPH OF SAMPLE 7N 1/2 @ TEN (10) INCHES WATER PRESSURE

Figure 18

PHOTOGRAPH OF SAMPLE 7 N 2 1/2 @ TEN (10) INCHES WATER PRESSURE

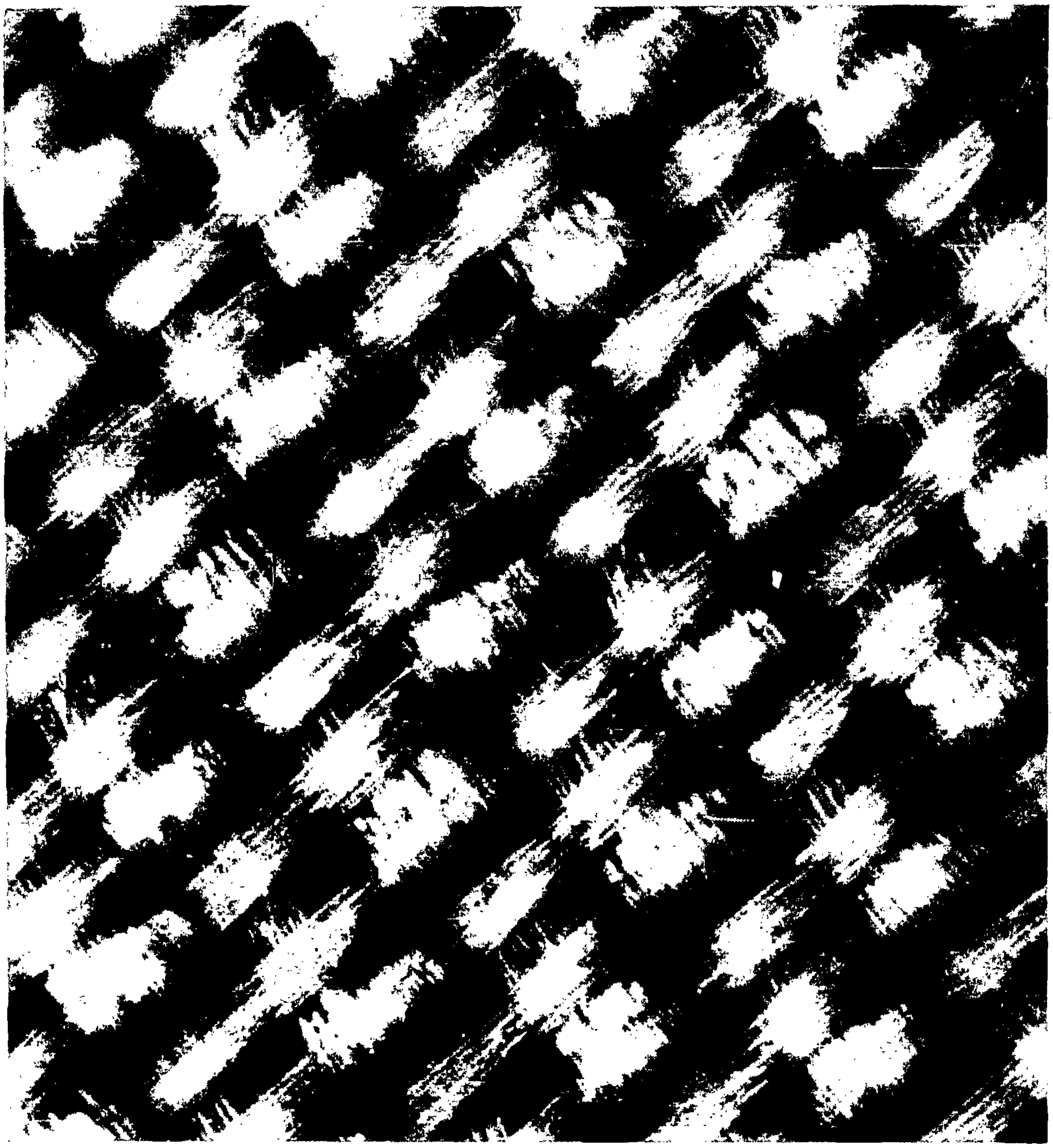

Figure 19

PHOTOGRAPH OF SAMPLE 7N 5 @ TEN (10) INCHES WATER PRESSURE

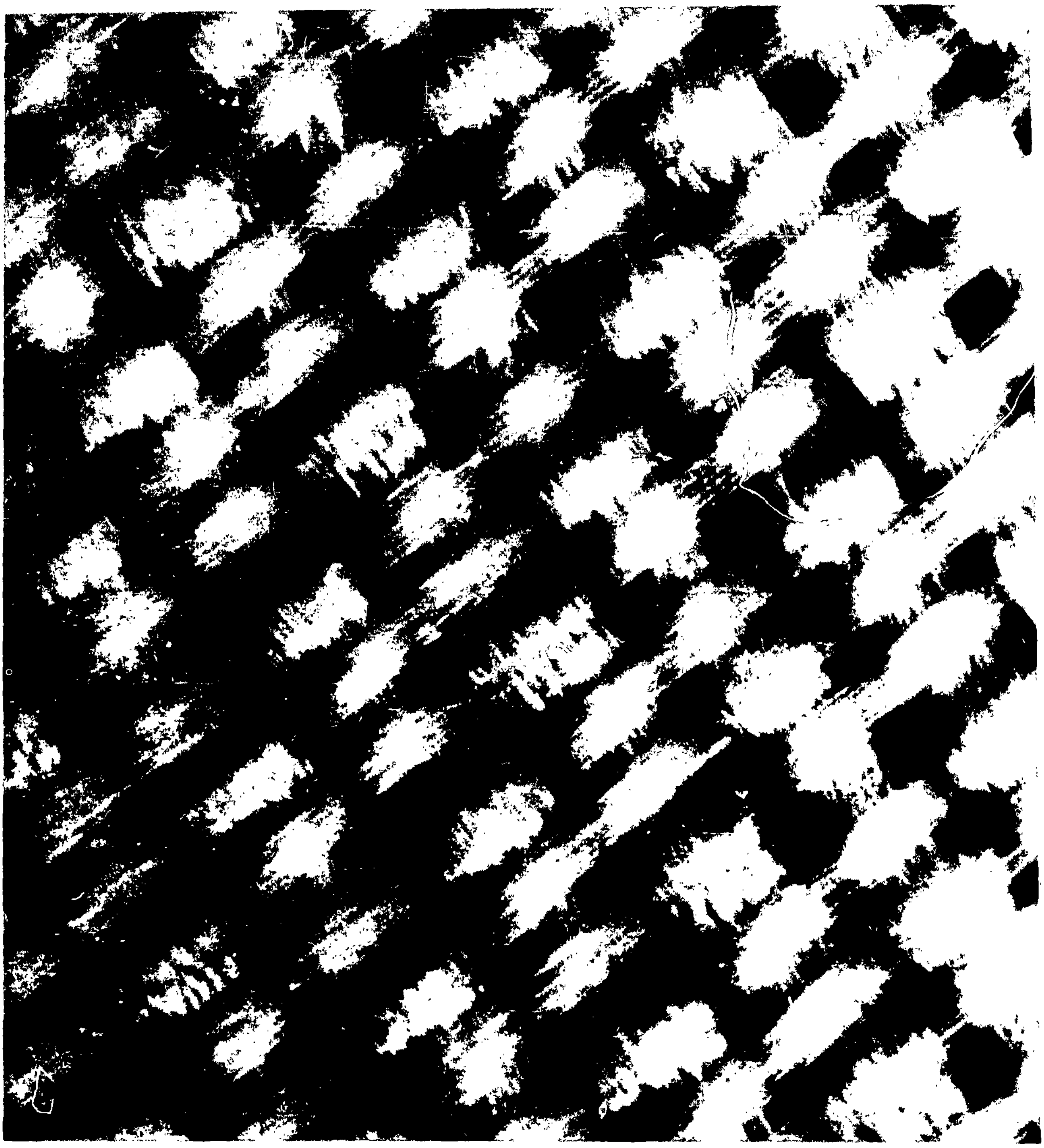

Figure 20

PHOTOGRAPH OF SAMPLE 7N 7 @ TEN (10) INCHES WATER PRESSURE

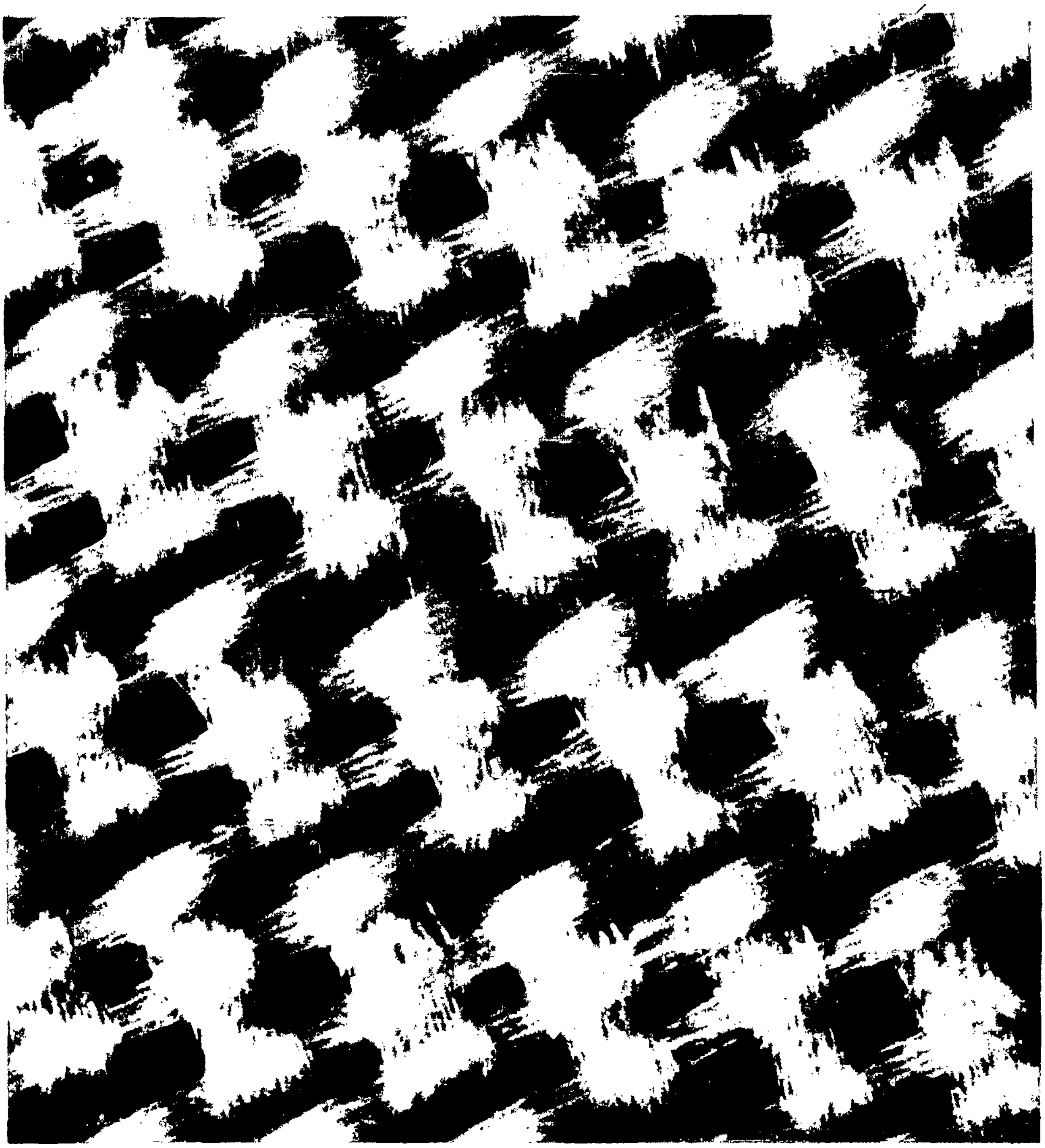

Figure 21

PHOTOGRAPH OF SAMPLE 7N 15 @ TEN (10) INCHES WATER PRESSURE

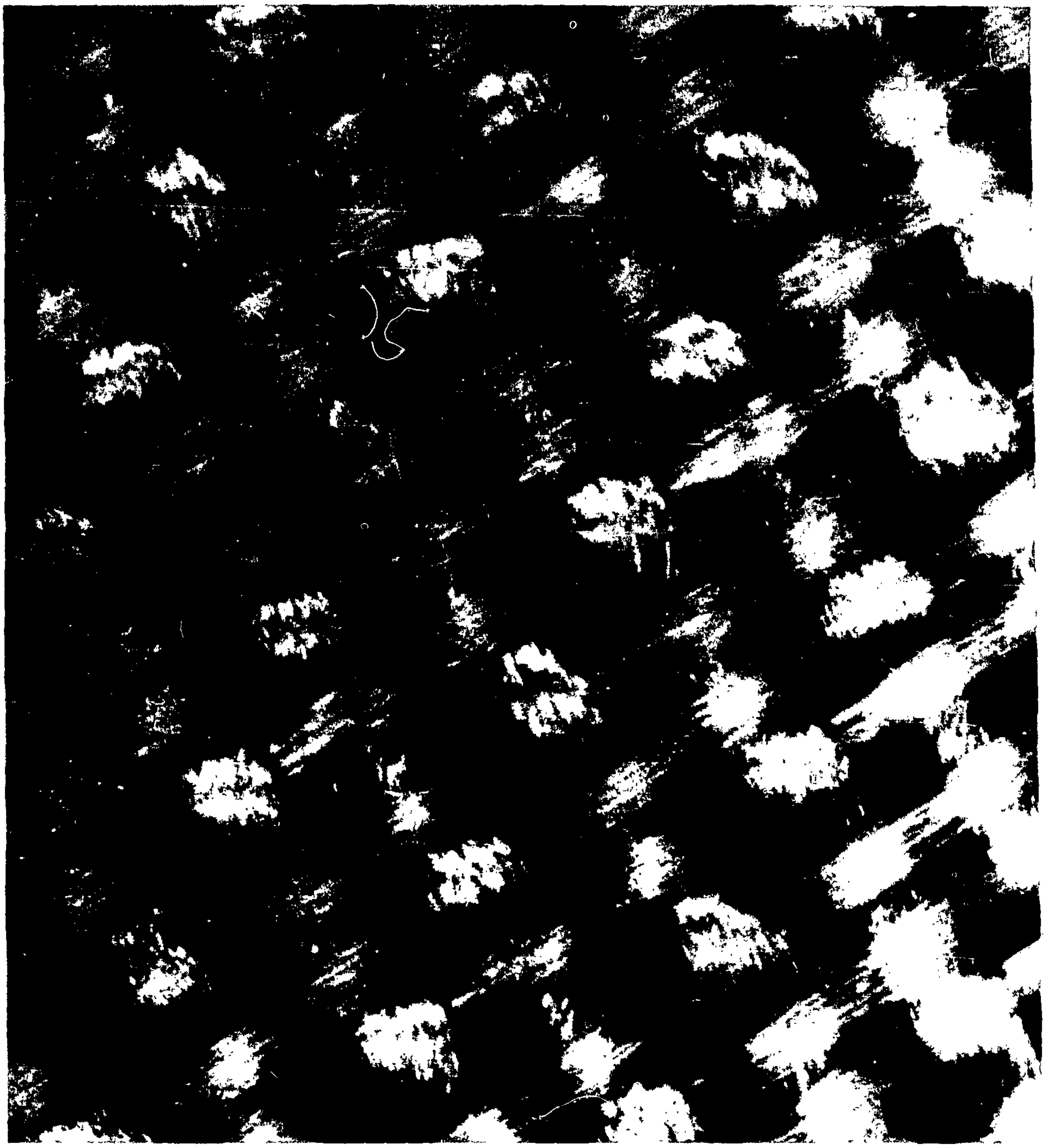

Figure 22

PHOTOGRAPH OF SAMPLE 7N 20 @ TEN (10) INCHES WATER PRESSURE

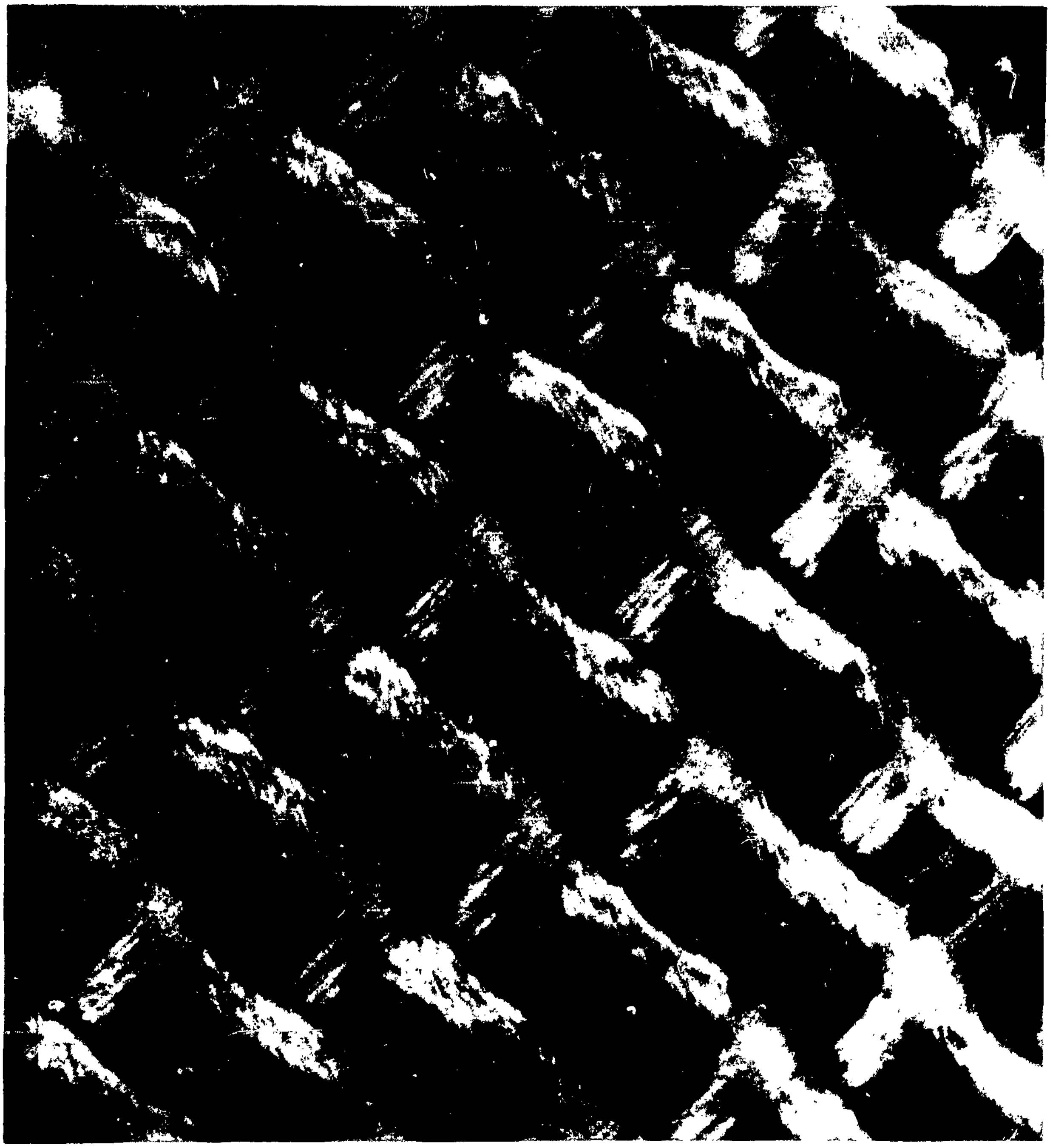

Figure 23

PHOTOGRAPH OF SAMPLE 7 N 35 @ TEN (10) INCHES WATER PRESSURE

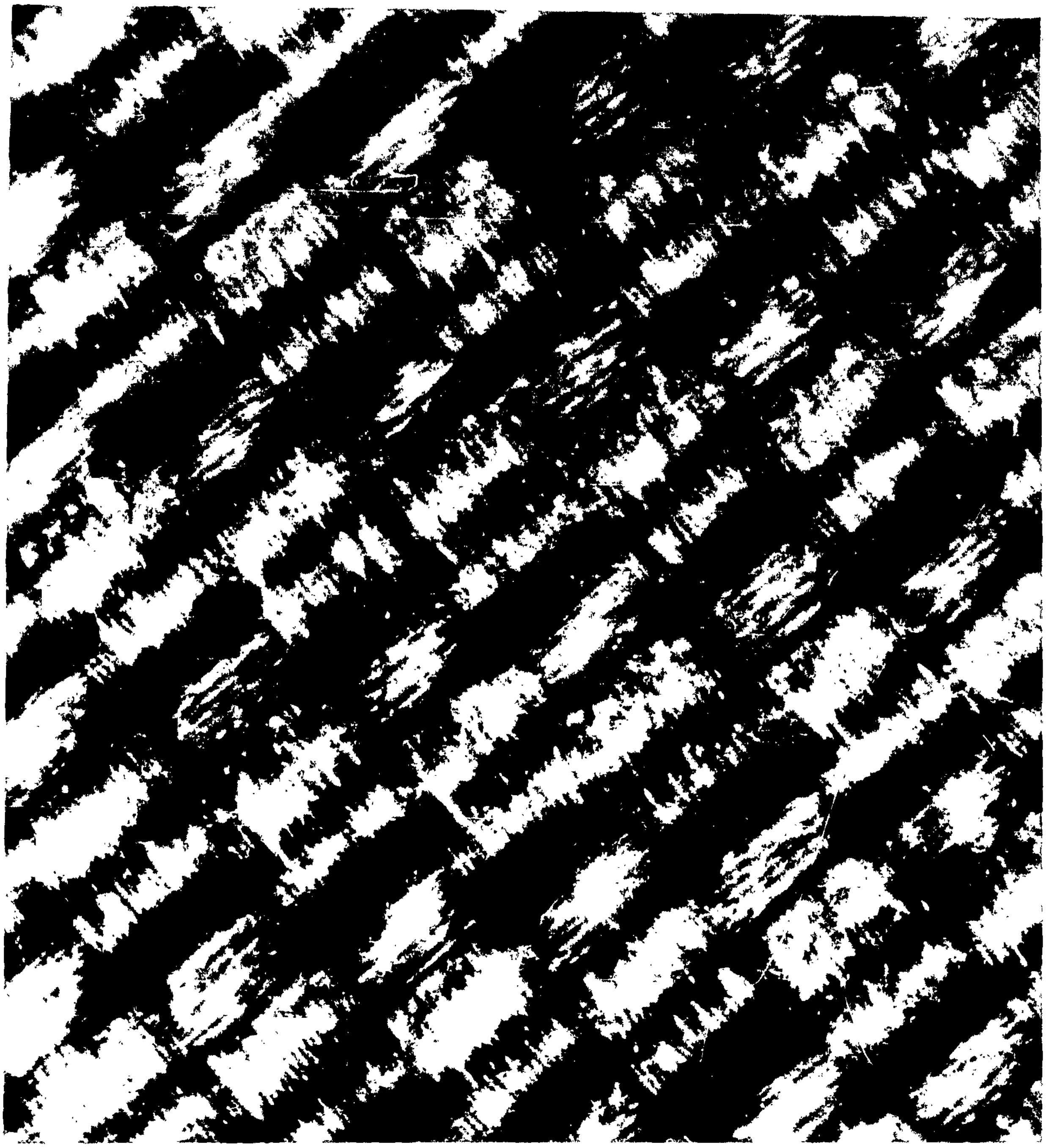

Figure 24

PHOTOGRAPH OF SAMPLE 10C 1/2 @ TEN (10) INCHES WATER PRESSURE

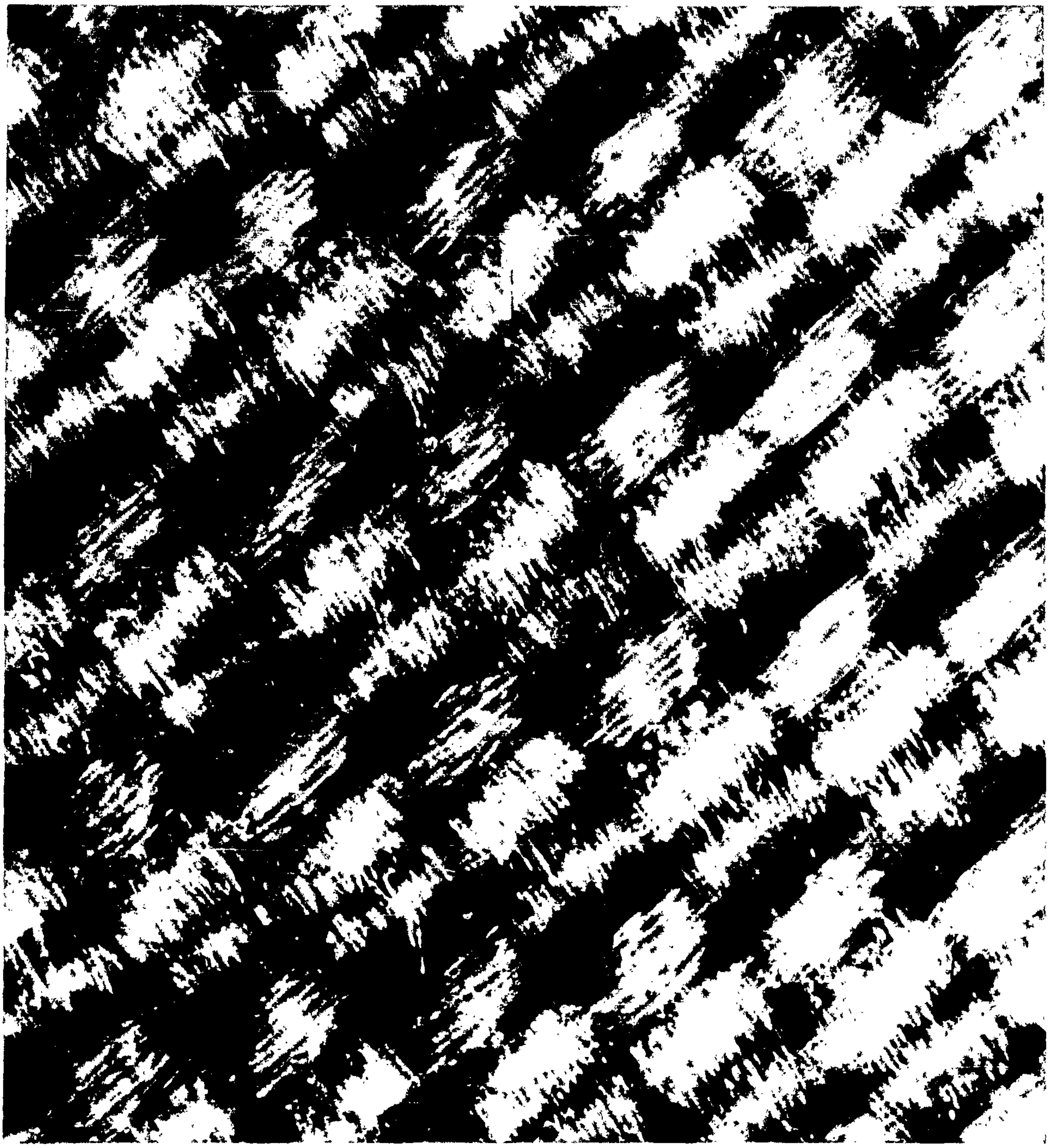

Figure 25

PHOTOGRAPH OF SAMPLE 10C 2 1/2 @ TEN (10) INCHES WATER PRESSURE

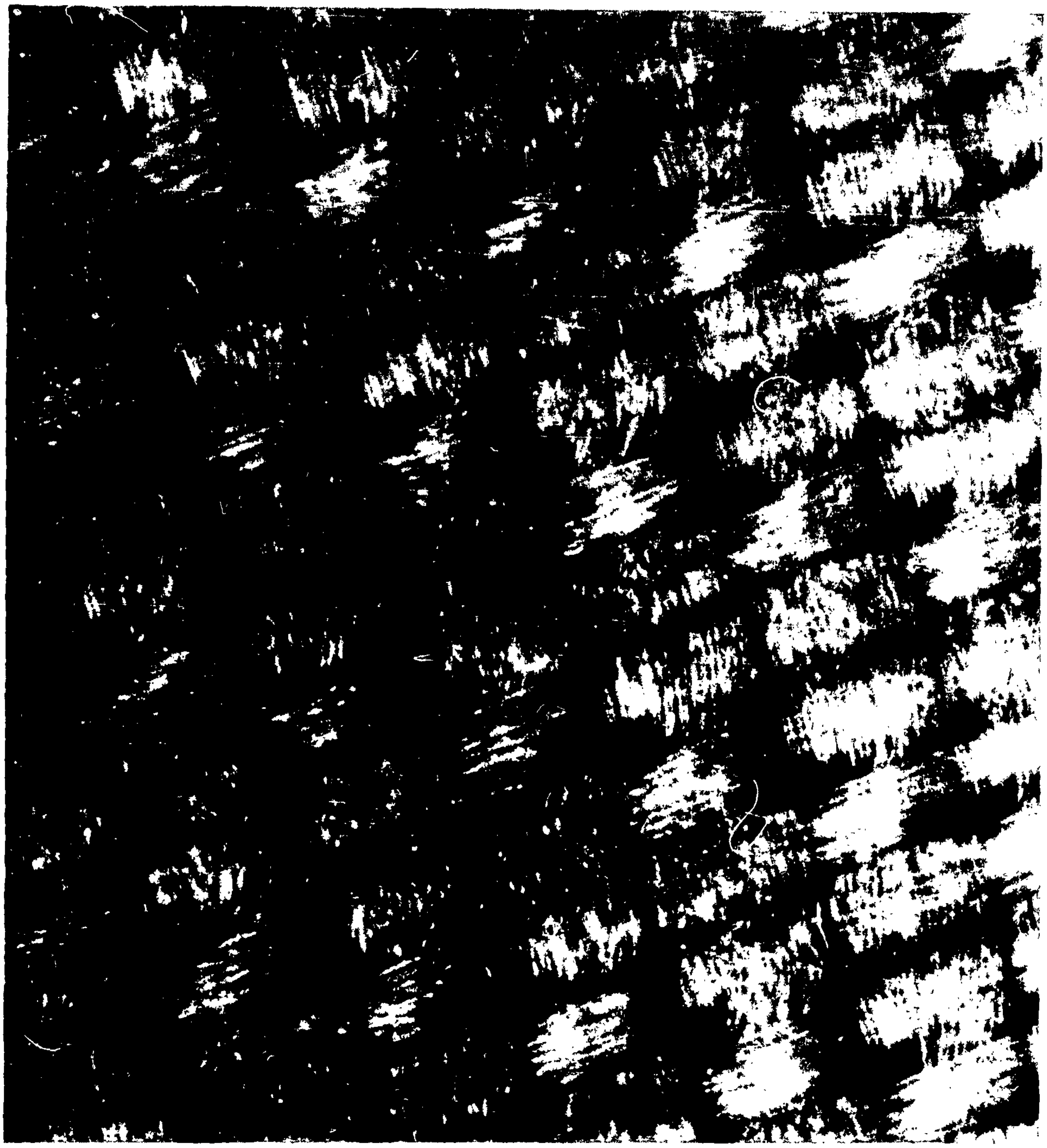

Figure 26

PHOTOGRAPH OF SAMPLE 10C.5 @ TEN (10) INCHES WATER PRESSURE

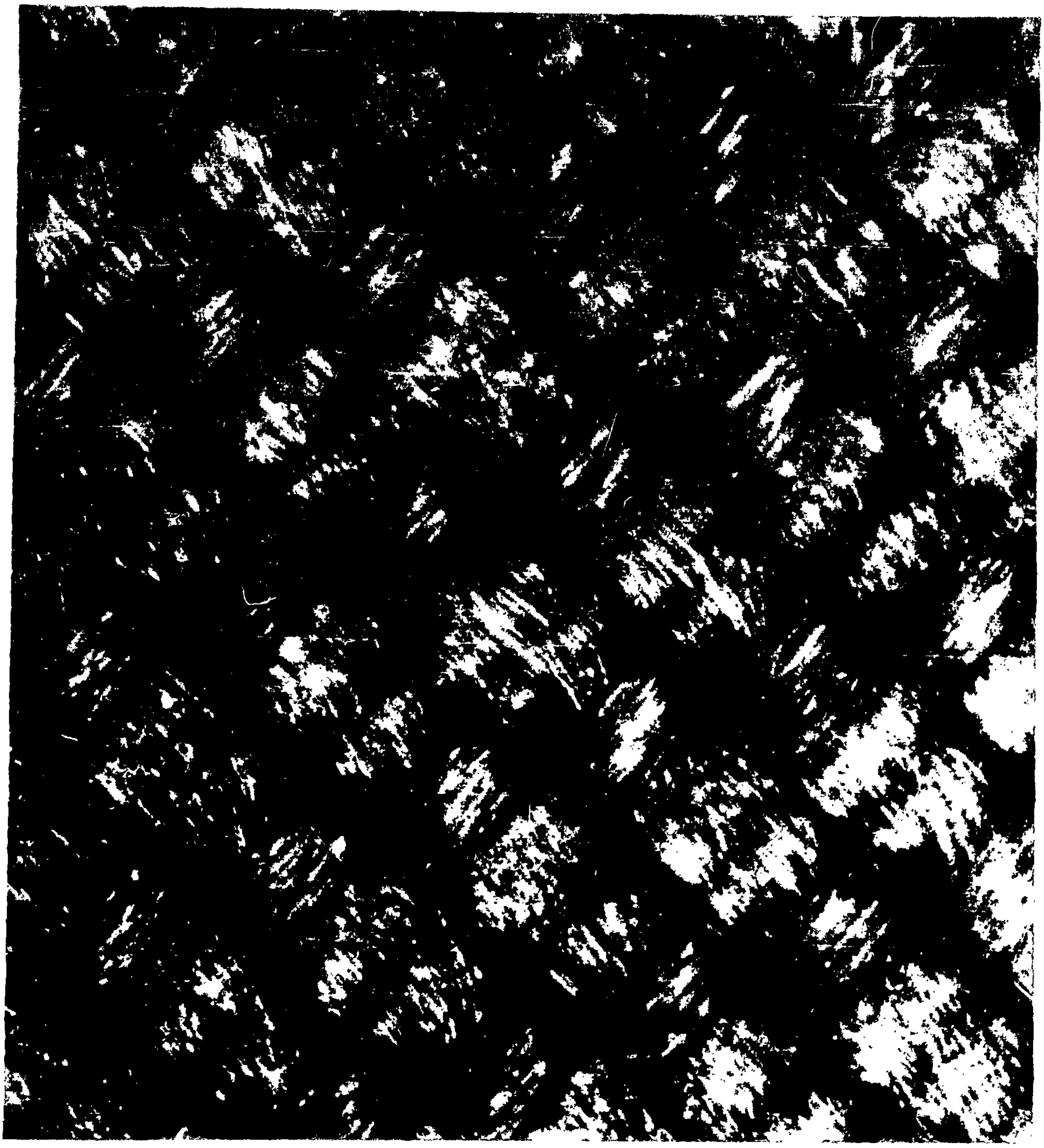

Figure 27

PHOTOGRAPH OF SAMPLE 10C 7 @ TEN (10) INCHES WATER PRESSURE

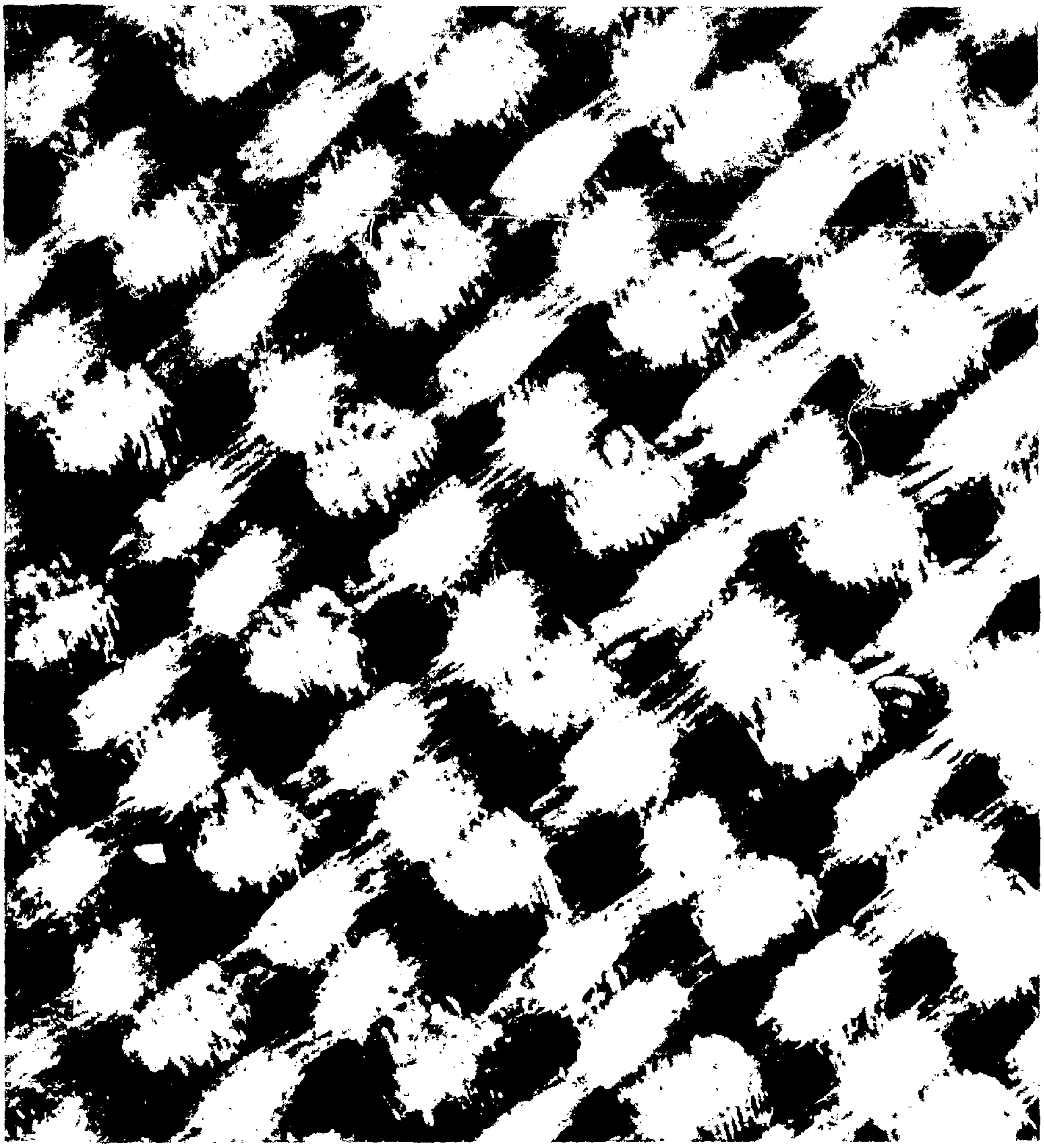

Figure 28

PHOTOGRAPH OF SAMPLE 10C 15 @ TEN (10) INCHES WATER PRESSURE

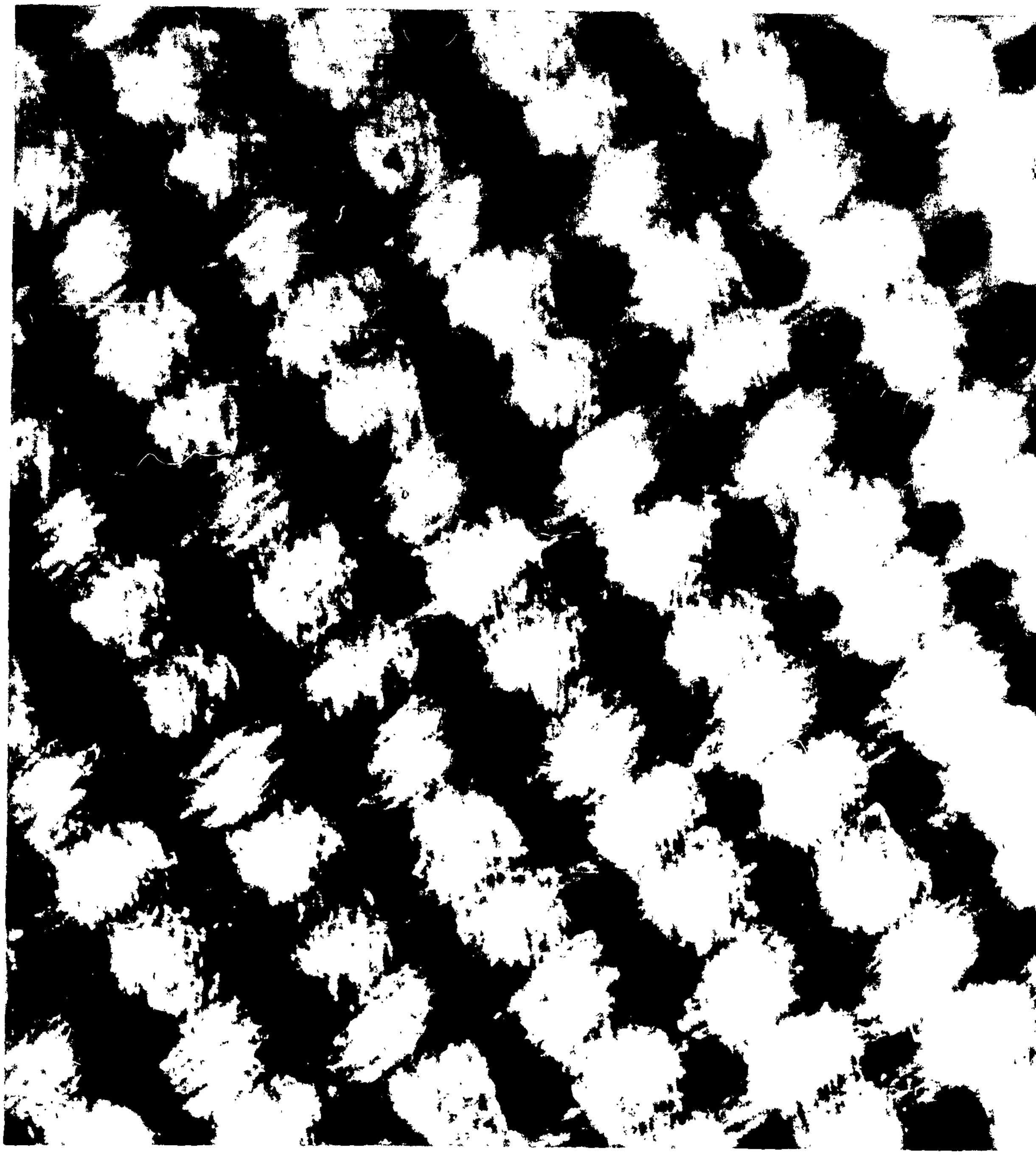

Figure 29

PHOTOGRAPH OF SAMPLE 10C 20 @ TEN (10) INCHES WATER PRESSURE

Figure 3C

PHOTOGRAPH OF SAMPLE 10C 35 @ TEN (10) INCHES WATER PRESSURE

Figure 31

PHOTOGRAPH OF SAMPLE 1CN 1/2 @ TEN (10) INCHES WATER PRESSURE

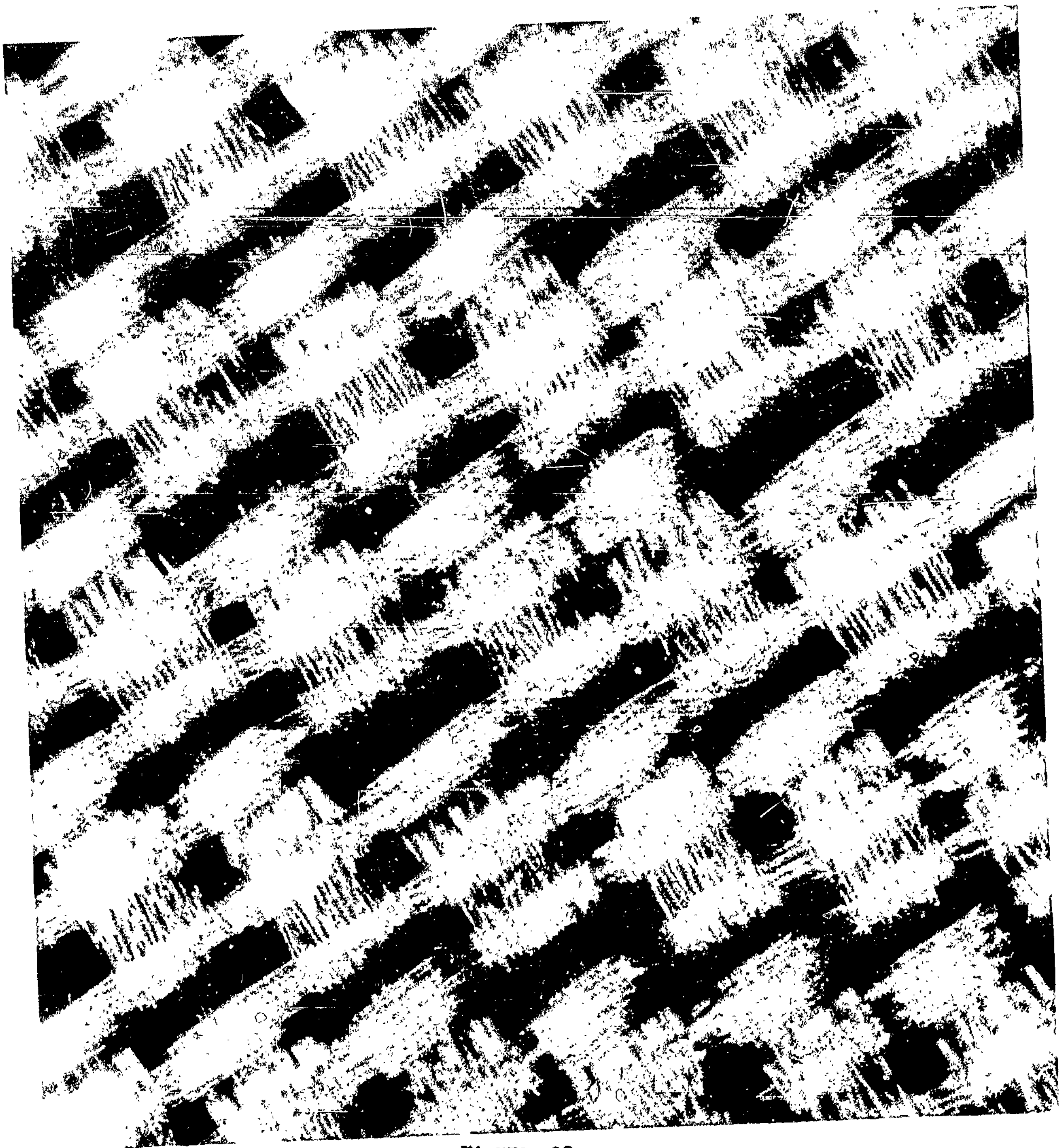

Figure 32

PHOTOGRAPH OF SAMPLE 10N 2 1/2 @ TEN (10) INCHES WATER PRESSURE

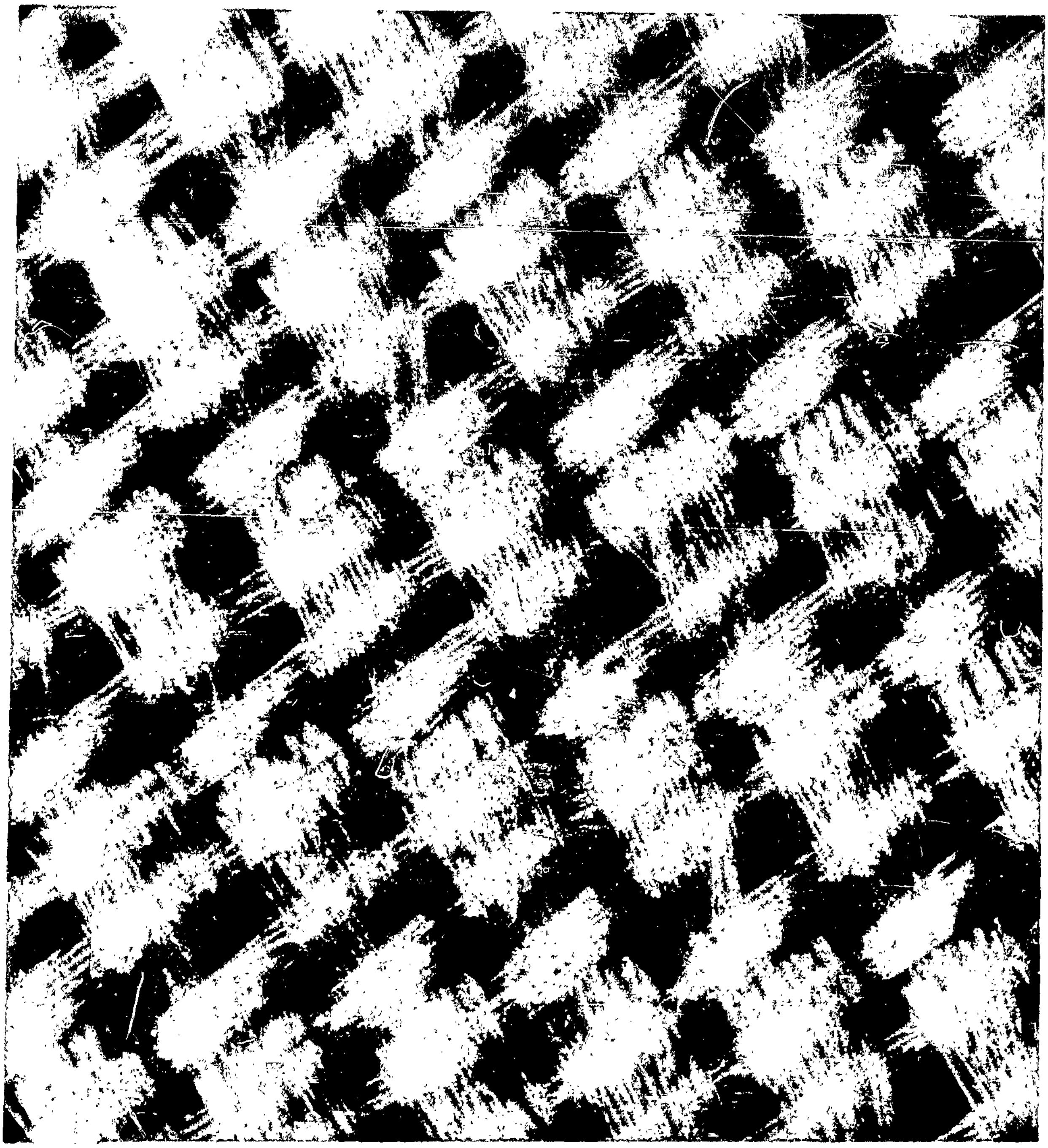

Figure 33

PHOTOGRAPH OF SAMPLE 10N 5 @ TEN (10) INCHES WATER PRESSURE

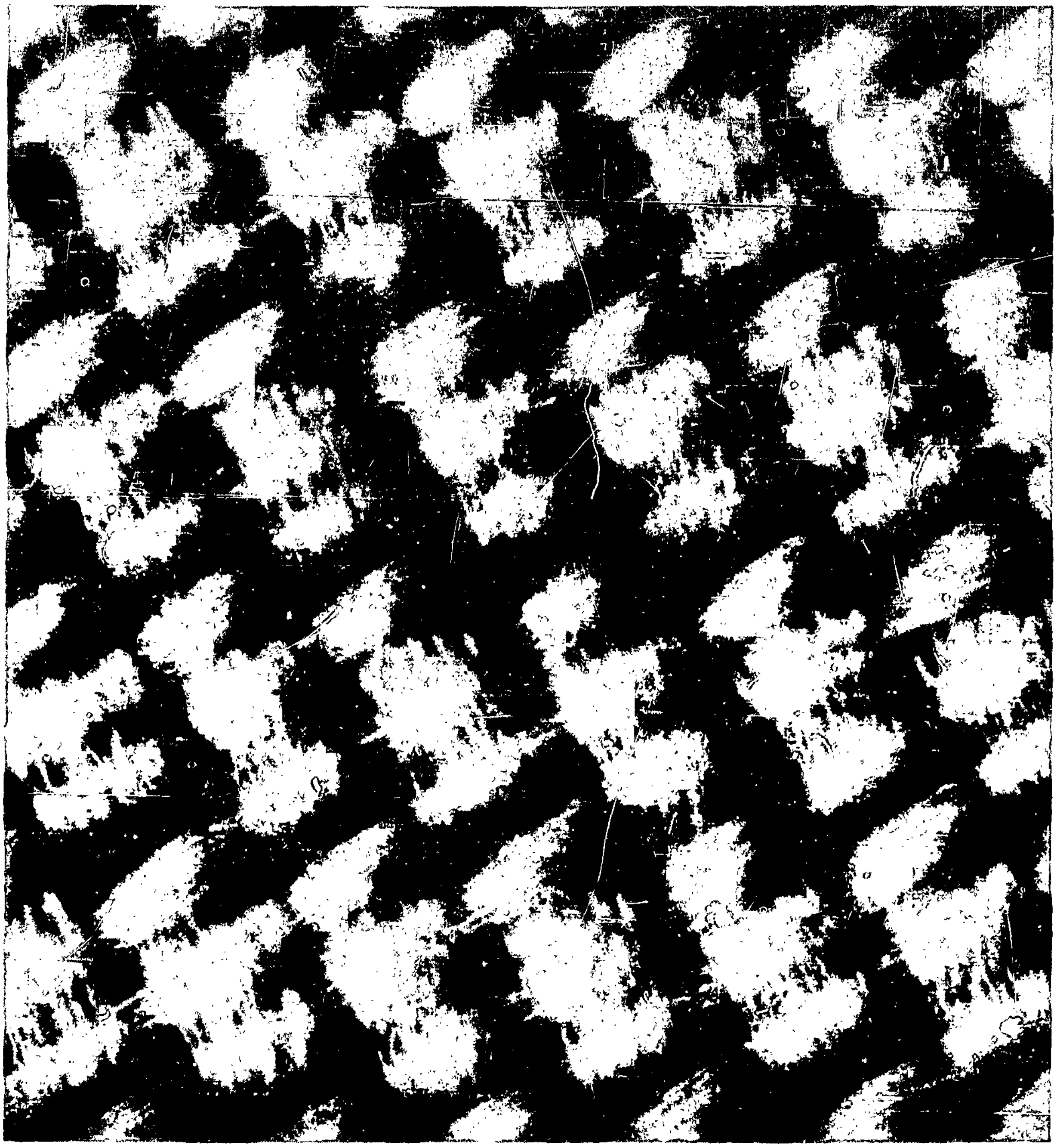

Figure 34

PHOTOGRAPH OF SAMPLE 10N 7 @ TEN (10) INCHES WATER PRESSURE

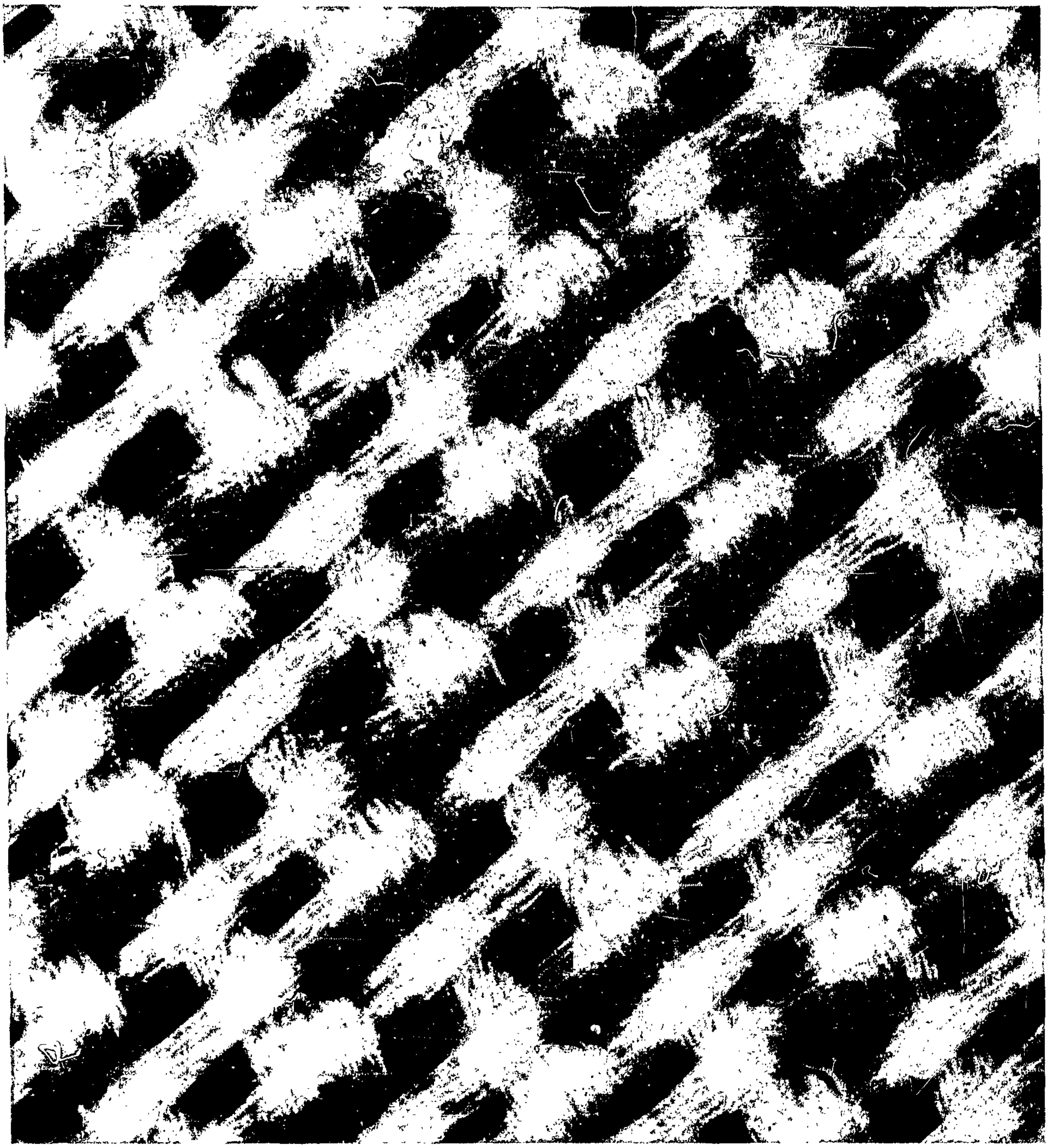

Figure 35

PHOTOGRAPH OF SAMPLE 10N 15 @ TEN (10) INCHES WATER PRESSURE

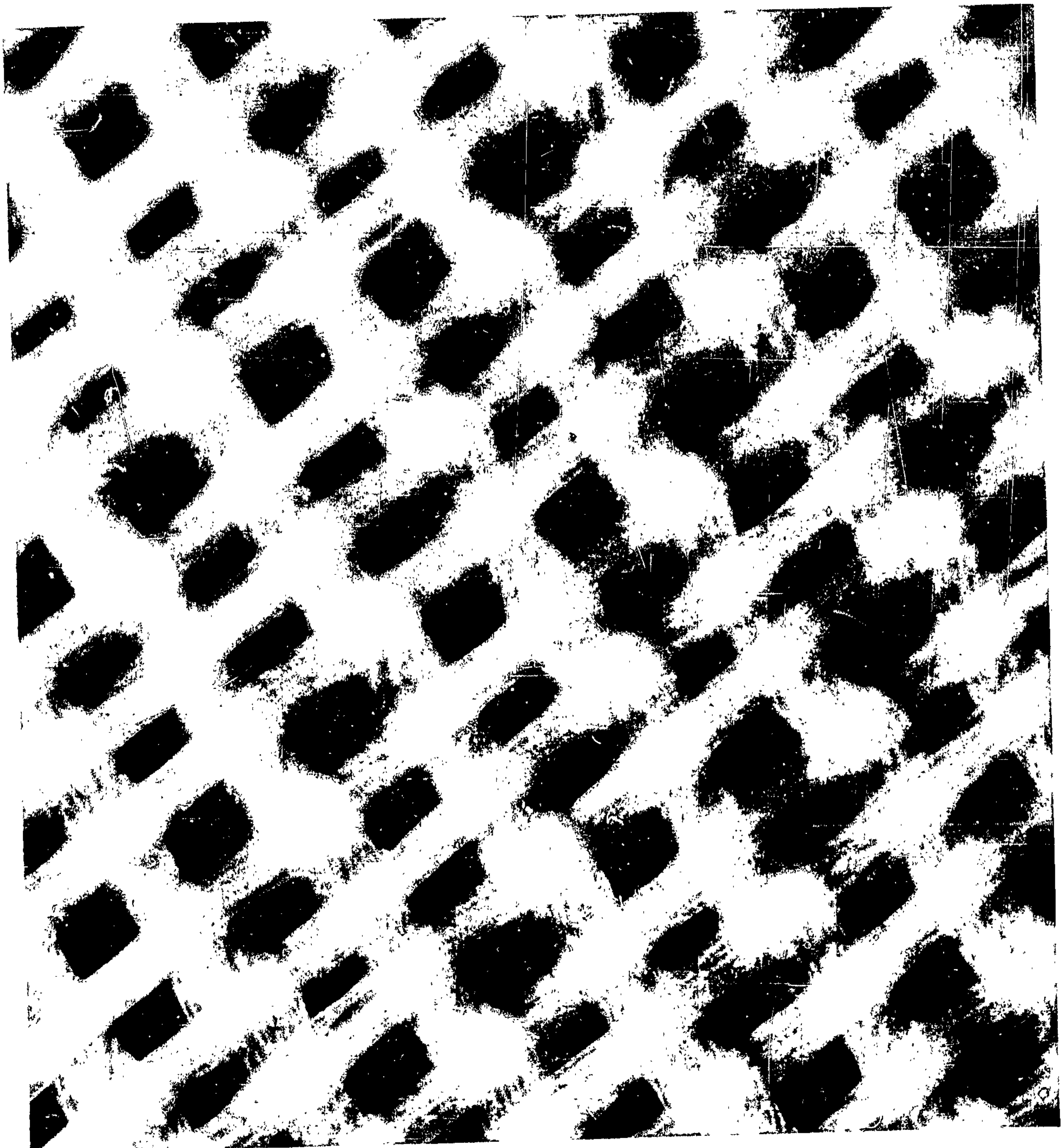

Figure 36

PHOTOGRAPH OF SAMPLE 10N 20 @ TEN (10) INCHES WATER PRESSURE

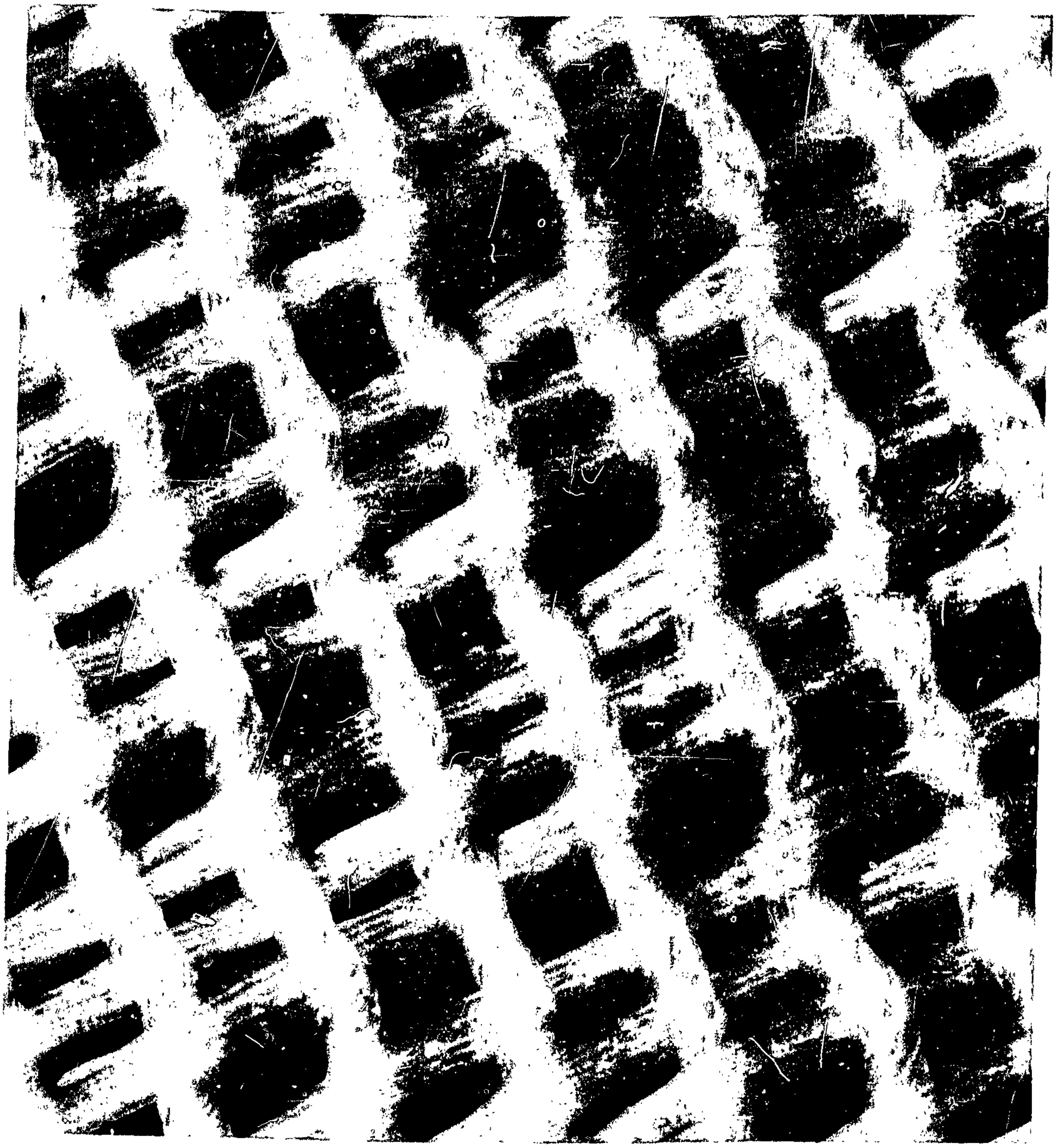

Figure 37

PHOTOGRAPH OF SAMPLE 10N 35 @ TEN (10) INCHES WATER PRESSURE